

A Spatially-Variable Fertilizer Applicator System

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Abstract

This thesis was submitted to the University of Cape Town in full fulfillment of the requirements for the degree of Master of Science in Engineering. I declare that I, Rebecca Eatock, have not submitted this thesis in this, or any other form, for a degree at any University and that this is my own work.

Signed by candidate

Signature of candidate

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Chapter 1

Background and Introduction

1.1 Terms of Reference

The Spatially Variable Fertilizer Application Project (SVFAP) was commissioned by Mr Clive Thorpe, General Manager of Kynoch Fertilizers in the Cape Region in February 1992. This work was requested due to Kynoch's interest in the topic of Site Specific Farming (also known as Spatially Variable Agricultural Production Systems: SVAPS or Prescription Farming). Kynoch hoped to utilise 'site specific tools' as a commercial service for the spatially variable distribution of their fertilizers.

It appeared as though the following steps were required for the process of spatially variable fertilizer distribution:

1. Determine the crop yields at different positions throughout the field.
2. Take soil samples at designated positions in order to determine whether the crop yields correlate with the nutrient levels within the soil.
3. Process the above information into a suitable form.
4. Evaluate the needs of the field and establish fertilizer recommendations for the different regions of the field.
5. Adapt the fertilizer applicators to facilitate the spatially variable application of fertilizers.

Kynoch recognised the need for a suitable positioning technique for this project. It seemed that position information was required for crop yield map development,

soil sample positions and for the determination of the correct fertilizer application rates based on the position within the field.

Kynoch therefore required that some research to be carried out and that the required technology be developed and tested. Kynoch's requirements for the Spatially Variable Application Project were therefore:

1. to investigate the general topic of Site Specific Farming. The technologies relevant to the SVFAP needed to be chosen and evaluated. It was hoped that this investigation would also establish the feasibility of implementing a commercial service to distribute fertilizers spatially variably.
2. to establish which positioning technique would be most suitable for this project.
3. to implement practically those steps of the project not requiring agronomic expertise. The chosen technology and system design for each step of the SVFAP was to be tested experimentally. It was hoped that this exercise would provide practical insight and determine the feasibility of the selected techniques. As an engineering project, it would not be required to make fertilizer recommendations.

Kynoch required that all the design work and experiments be carried out within the framework of a system design suitable for a commercial implementation. This system design had to be decided upon. As each of the steps of the SVFAP were sequential, the commercial system design required that the hardware for each step of the SVFAP be suitable for use in the other steps. This would ensure as little additional cost as possible.

1.2 Project History

After the user requirements were identified and confirmed in a requirements review meeting, attempts were made to translate them into the engineering context. The user requirements were therefore categorized into the literature review, design and implementation phases required of a masters thesis or an engineering project. The most likely system definition and work breakdown schedule was proposed. The proposed system definition was to be flexible but still ensure that the correct context and perspective be kept on the project. The system definition was particularly useful in the literature review in identifying which aspects of site specific technology were relevant to our project.

The following six months were spent investigating the topic of site specific farming in general. All technologies relating to the various steps of the SVFAP, were investigated. In addition, information relating to previous work done in spatially variable application was collected to assess the feasibility of the project.

This literature review involved an on-line search through the library's access to international databases containing references to literature on the topic. Information was added as it became available throughout the duration of the thesis. Much of the collected information made reference to other sources of data. Finally, after all the experimental testing had been carried out and the work for the thesis was at an end, a trip to the USA provided further clarification and more detail to the information already gathered. The trip to America was facilitated through the opportunity of presenting a paper and the visiting of various institutions involved in this work.

This investigation gave a very good indication of the diversity of site specific practices. The study enabled the identification of those technologies which were worth further investigation and those which were not practical at the time of this investigation. After all the available options were established, the general system definition remained unchanged although the various components had received far greater detail and clarification.

The phase following the literature review was to detail the system definition and test these solutions experimentally. The method of testing was to implement the solution for each of the steps, as stipulated in the user requirements for the SVFAP. Before any of these steps could be implemented, various tests were carried out on the chosen positioning technique in the agricultural environment. The equipment was taken on loan and software written to log the positioning data in the field and post process it. A thorough knowledge of the positioning technology was required in order that the necessary tests could be identified and the results correctly interpreted. Local conferences provided valuable information in this regard. For these tests to be successful, a fair proficiency in programming and some surveying knowledge was also required.

Soil sampling was also implemented in the same set of field tests. The post processing involved in these tests was intensive. Programs were written to implement the relevant geostatistical techniques for the manipulation of the soil sampled data into a meaningful form. A course was taken in Geographical Information Systems (GIS) for the manipulation and representation of data.

The collection of crop yield data during harvesting was also implemented in another set of field tests. Data logging programs were modified, a combine harvester instrumented with a grain flow meter and the positioning technology again implemented in these tests. Harvester modelling, new post processing software and

extensive use of a GIS was made for the interpretation of the findings of this test.

The processing of gathered information into a suitable form, was also achieved through these tests. The thesis write up was undertaken whilst the harvesting data was being processed. The decision to write up at this juncture was taken due to amount of relevant results that had already been acquired.

Due to the fact that this is a commercial project, sponsored and commissioned by Kynoch Fertilizers, it is an ongoing project. Crop yield maps have since been generated. A system prototype is being commissioned for the commercial generation of crop yield maps and for further testing. The adaptation of a fertilizer applicator for the spatially variable application of fertilizers is also being investigated.

1.3 System Definition

A system configuration was required to facilitate the logging of soil sample and crop yield data and to control the spatially variable application of inputs (fertilizers). The other more analytical work, could be implemented away from the field by combining computing resources with expert agronomic knowledge. Some of these analytical functions were within the scope of this project in that the field data had to be presented to the agronomists in a processed form. This project is therefore concerned with providing the tools with which the goal of spatially variable fertilizer application can be achieved. This work does not attempt to make agronomic assessments except where it directly relates to the tools being developed.

The system definition describes the way in which the hardware was to be used in the field (and on the vehicles). This hardware was to be used for soil sampling, harvesting and for fertilizer application. The vehicles to be used were therefore the soil sampler, combine harvester and fertilizer applicator respectively. The system definition to be used, is described in Figure 1.1. Detailed descriptions of the groups of hardware and their block diagrams are reserved for the later chapters when the testing procedures are described.

Spatially variable systems can be implemented as 'automatic' (real time) or 'temporally separate' (map-based) systems. An 'automatic' system would have soil sensors at the front end of the fertilizer applicator. On-board analysers would then process the soil samples and control the amount of fertilizer applied as the vehicle moves over the field. Stored crop yield information would then be combined with the chemical status of the soil at each location in determining the application rates. Such an automatic solution is not feasible in practice due to

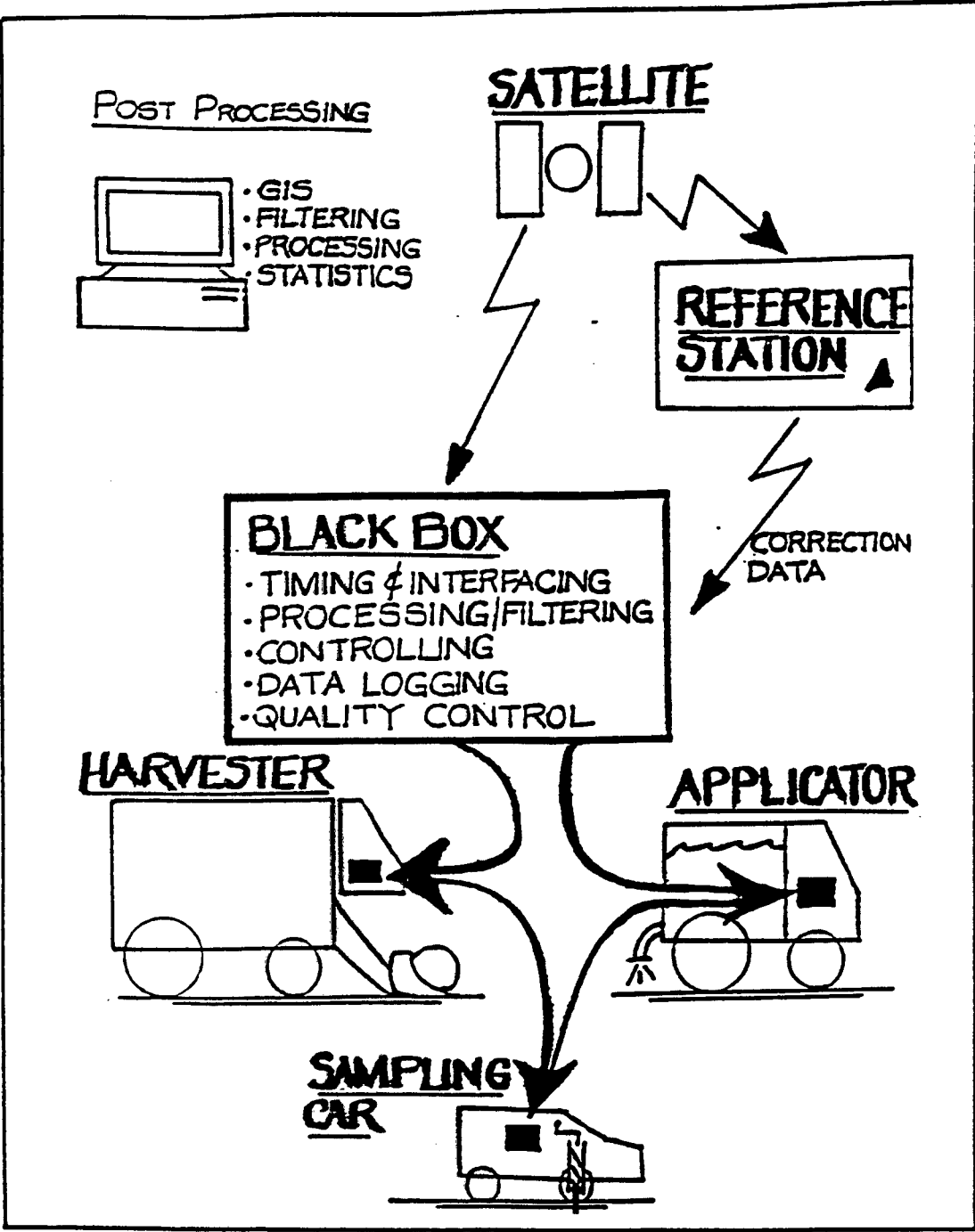


Figure 1.1: Spatially Variable Applicator System

the fact that very few real time sensors have been developed for measuring all the nutrients of interest.

Our system definition is based on a ‘temporally separate’ design. This means that the acquisition of field data and fertilizer application occur separately, not simultaneously. The advantage of this is that *many* field attribute maps (soil sample and yield results for example) can be developed to assist fertilizer recommendations.

Soil sampling, yield mapping and fertilizer application requires accurate positioning information. The positioning technique will provide the spatial referencing for map generation and serve as a pointer to the required application rates based on the position in the field. Considering the operating environment, a satellite based positioning technique was thought to be most suitable. This was confirmed during the literature survey. The receivers were to be used in a differential configuration. This required that one receiver of satellite signals, be set up at a reference station, and the other on the vehicle. The reference station would be at a more remote high site in the vicinity of the vehicle. The two receivers would receive the same satellite signals. There would also be telemetry set up between the receivers so that the reference station could communicate with the mobile station on the vehicle. A more detailed description of this differential satellite positioning technique is given in Chapter 2.

All the hardware common to soil sampling, yield mapping or fertilizer application was to be combined into a ‘black box’ which would be portable between the vehicles. This would include the satellite receiver and a dedicated computer for example. The ‘black box’ would need to be controlled by software and operate in a certain mode depending upon the functions required on that particular vehicle. Peripheral equipment, specific to the current task, would also need to be connected to the ‘black box’. The ‘black box’ would therefore suit the sponsor’s requirement for an economical solution in reducing the amount of redundant equipment.

The ‘black box’ solution would be required to carry out a variety of hardware and software related functions. These would include system timing and interfacing, data logging and processing, control and quality control functions.

1.4 Introduction

The aim of the Spatially Variable Fertilizer Application Project was to investigate and implement selected Site Specific Farming practices for the different phases required by the project. Site Specific Farming is the activity in which various

technologies and procedures are implemented to cope with the variations that exist *within* fields. Conventional farming practice dealt with fields as whole units; each field receiving the same treatments throughout.

There are two main motives for developing agricultural systems that operate spatially within fields. The first is due to the expected increase in crop yield due to the more efficient use of agricultural inputs and recourses. The major advantages however, are the environmental benefits due the reduction of residual nitrogen and other harmful chemicals leaching into the ground waters.

Very little site specific farming has been researched or implemented locally. Certain aspects of site specific practice have been justified and tested overseas. A fair amount of success has been achieved in Germany, Britain and the USA. The purpose of developing these tools locally was to facilitate maintenance, equipment and personnel availability and to ensure a system development that is locally understood and maintainable.

This project was required to fulfil the requirements of an MSc in Electrical Engineering. It was simultaneously required to be developed with the view of it being implemented as a commercial service for Kynoch Fertilizers, who were the sponsors of the project.

The project steps were specified by the user as:

1. determining the crop yield at the different positions throughout the field.
2. taking soil samples at designated positions in order to determine whether the crop yields correlated with the nutrient levels within the soil.
3. processing the above information into a suitable form.
4. evaluating the needs of the field and establishing fertilizer recommendations for the different regions of the field.
5. adapting the fertilizer applicators to facilitate the spatially variable application of fertilizers.

From this it can be seen that the Spatially Variable Fertilizer Application Project does not deal with the last step only. There is a great deal more work that needs to be done to fulfil the goal of spatially variable application.

The aim was specified as providing the technology or tools required by each of the above steps. From the engineer's perspective then, the step in which the results of the soil sampling and harvest are analysed for fertilizer recommendations, is delving into a whole new discipline. It is for this reason that the agronomic aspects

of the project were avoided except where they directly affected the development of the tools for the other steps.

In accordance with the user requirements and the project development, this document will first relate the findings of the investigation into the field of site specific farming. All site specific farming practices relating to soil sampling, yield mapping, information processing or fertilizer application are discussed. The remainder of the thesis deals with the positioning technique feasibility tests and the implementation of the soil sampling. A description of how the data was processed into a suitable form, the test findings, results and conclusions are also presented in this document.

The thesis ends with a list of ideas or avenues of further research. The software coding was printed out and added as an appendix because this document was required as both a thesis and a report to the project sponsors. The results of laboratory tests and other agronomic results were also relegated to appendices because these activities were background to this thesis.

This document therefore begins with a chapter describing the investigation into the various topics of site specific farming. Descriptions of site specific farming considerations and techniques that touch upon this project in some way, are given in this chapter. Some of these topics are dealt with superficially if they were impractical or not of immediate relevance at the time of this investigation. These topics were included to remind the reader of their potential relevance and to serve as a pointer to the significant criteria. Other topics were dealt with more comprehensively if they had future potential or if they seemed to be the most likely solution for our application.

Certain information from the literature review could be collated and further conclusions reached. These deductions were related to the next chapter. Both the literature review and the associated deductions are discussed under the topics of: basic agronomic considerations, the theory and feasibility of positioning techniques, progress already made in spatially variable application projects and the constraints of the project in the local context.

The rest of the thesis deals with the methods, findings and conclusions of the first set of field tests which took place. The first chapter contains the detailed specification of the system definition for the experiments as well as the methods and preparation for the tests. The findings of the various positioning technique feasibility tests and those of the implementation of the soil sampling phase are related in the following chapter. The post processing of these findings into meaningful results, the use of geostatistical techniques and a discussion of the results is given in a separate chapter before conclusions are drawn.

Chapter 2

Investigation of Site Specific Farming

This chapter relates the findings of an investigation into the topic of Site Specific Farming. All aspects of Site Specific Farming were touched upon, including technologies used and the practices and procedures required for the treatment of field spatial variability. Certain areas were covered superficially if they were not practical at the time of this investigation or if they were beyond the scope of this project. Promising areas for use in the SVFAP were covered more extensively.

This work is the product of a search for literature through international library databases, input from the sponsors themselves, having access to the relevant equipment, involvement with the SA GPS User Group, conference attendance and an investigative tour of the relevant institutions in the USA (see Appendix K).

Agronomic considerations are first examined, followed by a discussion of the theory and feasibility of positioning techniques and of previous progress made in similar projects. Finally the constraints of developing the SVFAP in the local context will be discussed.

2.1 Agronomic Considerations

Agronomic considerations include the fundamental agronomic theory required for the determination of spatially variable fertilizer recommendations. Suitable statistical techniques and spatial data representations are tools required for this purpose.

2.1.1 The Management of Field-Soil Fertility Variations

Expert agronomic input is required for the analysis of the field soil samples and yield data to generate the required fertilizer recommendation maps. This input is vital for the successful implementation of this project. It is, however, beneficial to have an understanding of the agronomic considerations affecting the implementation of the project phases and the determination of the maps used to drive the applicator.

Factors for Consideration in Assessing Field Variability and in Data Acquisition

The fact that soil property variations will exist in any field is undisputed. The task is to establish the extent to which the variations occur and the nature of the variation. These assessments will determine whether spatially variable application is worthwhile.

In studying the variation that exists within the soil, the following factors need to be taken into consideration:

The existence of plant nutrient (chemical) variations within a field is often because many fields are comprised of several soils. Each soil type has different nutrient supplying capabilities (or fertility levels). In addition, researchers have reported that variable yields have multiple causes. Some credit the variable yields to differences in the fertility levels between soil types. It is implicit in this that the fertility characteristic of various soil types would determine the nutrient status AND resulting yields within a field.

The results of a correlation of a chemical survey of a field (previously treated with uniform fertilizer applications) with the types of soil found throughout the field are presented in [11]. The chemical survey also correlated well with yield observations in that the highest yields were obtained in regions where the subsequent chemical survey indicated low concentrations of essential nutrients. It would seem that in this case, crop yield is largely determined by the soil type as opposed to most other soil properties and effectively determines the extent to which the chemicals will be utilized by the crop. This depicts the same theme of the close correlation between soil fertility (usually determined by soil type), chemical variability and the variable yields. Further correlations would indicate the effect of other contributory factors to the fertility or lack of fertility of the soil and other explanations for the absorption of chemicals.

If the story was as simple as this, all that would be required in making SV fertil-

izer application requirements would be to investigate which soil types are present and the residual nutrient levels in the soil. The complexity of the true situation is seen in that many other researchers attribute the variable yields not only to the variable soil types and their related fertility levels but also to other edaphic factors. In addition to this, it has also been found that yield variability is due to such physical effects as topography, hydrographic characteristics, soil depth, weather conditions and temperature differences. This is relevant as these factors will affect crop yield goals, the feasibility of implementing spatially variable agricultural techniques and fertilizer recommendations.

For example, hydrographic effects have been extensively researched in an effort to establish water-yield relationships. This is due to the fact that the lack of availability of water limits crop yields most significantly. It is known that it is essential that the amount of water stored in the soil at any given time, whether under irrigated or dry-land conditions, be known for good crop management. The one aspect of this is in the adequate development of irrigation strategies. The other is in the determination of seeding rates, fertilizer recommendations and yield estimates. Proper fertilizer management can also increase plant-water use efficiency.

Farming techniques have an impact on how the field data is collected. It is relevant, for example, in cases where contouring is implemented, as this determines how effectively a full boom-width of crop will be present at the header. Similarly, the type of harvesting technique (direct cutting or wind-rowing) may further complicate the acquisition of the yield measurements.

Farming practices for spatially variable agricultural production systems employed in the USA were also investigated. Particularly those techniques employed in the sampling process and in yield determination. The machinery, sensors and meters involved in taking these measurements and in distributing the fertilizers were also looked at.

With regard to the sampling techniques, fertilizer guidelines indicate that the sampling conditions (such as sampling depth, intensity and type) are determined by current research, required reliability of the sampled information and whether certain chemicals are commonly deficient or not. The less deficient chemicals are assigned general relationships between fertilizer response and soil test levels. If the system was to be extended to other agricultural applications, such as pesticide application, then the databases may need to be extended to include spatial pest infestation information for example. Interpolations are necessary on the data in order to determine the recommendations for any specific position.

Factors for Consideration in Developing Application Rate Maps

Fertilizers can be applied to supplement some of the major chemicals such as phosphorous, potassium or nitrogen or they could be used to alter the pH of the soil or the amount of trace elements within the soil.

Various factors need to be taken into consideration in the development of the application maps:

Factors taken into consideration in making fertilizer recommendations are soil type (loam, sand or clay for example) and texture, past yield records, climate, topography, soil depth, soil pH and the chemical concentrations as obtained from the soil samples. The soil hydrology and previous soil usage is also taken into consideration. *Previous* soil usage refers to whether the field had lain fallow (whether cultivated or uncultivated) or was previously planted with some other crop (like lucern for example) so as to alter the demands made on the field. It is also said that site specific information, such as specific differences in soils, climate or management procedures, should also be used to develop the guidelines if such information were available. Literature on fertilizer guidelines however indicate that the yield potentials and soil test levels provide the essential data in determining the recommendations.

The best yield improvements can be expected in fields where well correlated and large yield-chemical variations occur and which are mostly comprised of good soil types. Spatially variable application will most likely show its poorest performance in fields where poorer soil types are represented.

Agronomists working on this type of work stressed the point of how the yield prediction so much determines the fertilizer recommendation. A Missouri agronomist indicated how the prediction and recommendation was a decisive toss up between the profit based or environmentally based motive in spatially variable fertilizer application.

A highly regarded statistician at Washington State University, is dealing with the problem of nitrogen application and has written papers to that effect (see [23]). It is easier to use your yield goals together with the immobile nutrient levels (P and K) to determine the recommended application levels. It seems however, that it is necessary to enter the leaching properties of nitrogen into the equation for the determination of nitrogen application levels.

Methods for Determining the Variability Within a Field

The field variations can be established through an analysis of the yield characteristics of the field, aerial colour photography, remote sensing, plant analysis and soil sampling:

- The most conventional technique used for accurately determining *yield* variances, is to use a yield measuring device (or grain flow meter) of some description. *Organic matter* sensing has been correlated with yield (or biomass estimations) and can therefore be useful in predicting yields and determining the required treatments. Real time organic matter sensors have been developed.
- Aerial colour photography can be used to determine the *yield* characteristics of the field. The results will, however be less accurate than the direct method of determining yield characteristics by means of a meter. Colour photography can also be used for determining the *moisture content* of the soil and therefore has hydrographic analysis applications if they are required. Other soil properties may be obtainable using this colour photographic technique (such as *erosion* characteristics and *soil texture*). It has been established that such techniques are unfortunately crop-age and moisture sensitive.
- Similarly, remote sensing using microwave energy (scatterometers for example) from satellites or aircraft can produce pictures which can be used to determine *vegetation* types and various other soil properties. These properties include *soil dielectrics* which is most often an indication of *moisture content*. It is argued, however, that other soil properties such as *soil type* could be determined if the spatial moisture content is known (similar to ground truth data acquisition).

The above discussion implies the possibility of using remote sensing for the determination of the homogeneity of the soil through the hydrographic data obtained. This has particular relevance to the determination of a sampling strategy (see later). Utilizing remote sensing for the purposes of monitoring crop growth or for the determination of localized *trouble spots* in yield are current and real applications. Remote sensing could be used in the confirmation of general field estimates if such data were available. It is however known that the vegetation canopy is too low to the ground for effective satellite remote sensing over most frequency bands. Therefore, as far as actually inferring spatial crop yields is concerned; the experts indicate that no such work has been done. In addition, the determination of *soil nutrient* levels has not yet become a feasible property to be distinguished from remote sensing techniques.

For the information that can be gleaned from remotely sensed images, satellites provide pictures with a pixel size of 10 to more than 1100 metres and 3 to 15 metre pixel sizes are common in aircraft based radiometric data. This is the smallest entity upon which estimates can be made and these estimates are limited in their accuracy depending on the resolution of information that can be determined from a pixel. Remote sensing has a more useful application in determining the general characteristics of large areas of land at any time. In summary it seems that remote sensing is an inexpensive means of obtaining information as well as providing the data at resolutions suitable for *some* within-field spatially variable applications. As this information still needs to be correlated with ground truth data to establish its credibility, it is as yet an unlikely means of within-field data extraction. Remote sensing does however have application for the *forecasting and monitoring of crop yields*, the *assessment of insect and drought damage* and the *determination of soil status and water properties* in general.

- As previously explained there are significant limitations in microwave satellite remote sensing for agricultural applications. Optical remote sensing however can provide valuable information about organic matter content (or biomass prediction) and the moisture content of the land. These determinations are made making use of the red, infrared and mid-infrared reflections. Theoretically and under laboratory conditions, the proportional relationship of biomass to yield has been proven and is crop dependent. The people at Washington State University however, said that they have not achieved the same correlations in practice due to other practical constraints such as straw on the ground, residual moisture etc. There are also other problems in that this technology is weather dependent and that there are delays inherent in obtaining these images. There is also still a lack of standard procedures within this field of research. Some believe in taking everything including the phase of the moon (quoting my prof.) as being significant effects on the image received. Others will simply use a pine forest as a reasonably good unchanging reference and process accordingly.

Despite the lack of convincing proof of absolute yield determinations within fields, the success achieved in showing 'trouble spots' and relative yield/biomass differences cannot be disputed. This can be most beneficial if these spots could be accounted for and corrected. NASA is currently planning and developing a satellite constellation (the remote sensing equivalent to GPS) that will cover the globe for frequent and fast remotely sensed data. This latter system should overcome most of the weather limitations and availability problems.

- The process of plant analysis is used for the *progressive analysis of the crop* and may have information beneficial to the agronomist for site specific

farming.

- The digitization of terrain relief is also useful for the determination of the *spraying patterns* of the applicators. This information would also assist the agronomists requiring the information for the *modelling of soil activities etc..* The results of the soil sampling, plant analysis, relief data and yield data can all be included into a complete GIS representation of a field.
- As far as the determination of the chemical composition of the soil is concerned, the major source of data acquisition for the system is likely to come from soil sampling as opposed to any other form of data acquisition. It should be noted however that there are relatively high costs associated with this intense soil sampling as well as a substantial time lag between sampling and data availability.
- It is also important to describe the field in terms of its size and irrigation procedures.

2.1.2 Processing and Analysis Techniques

It is important to understand how a SVFAP solution should prepare the information for analysis purposes. Specialized analysis techniques need to be used in the development of yield maps and for the yield-soil correlations. These correlations are required to determine whether variable application is justified.

Software Options

Once the data has been gathered and processed, the application maps need to be developed. This involves expert agronomic knowledge. Attempts have been made to incorporate not only the expert systems or decision support required to generate the application maps or field treatments, but also the statistical analysis, management grid generation and associated mapping of the spatial data into grids into a single software package. The details of such a package can be found in [38]. This project was initiated due to the need to provide a single package which can combine all the functions required by a SVFAP into one environment with one language and with one operating system. The previous implementations of the desired agronomic analysis usually required usage of a few separate packages including a GIS. In our experimental investigation, data acquisition and statistical analyses will still be carried out using whatever packages and technology is available (with a GIS amongst these). The analysis by the agronomists will be

determined based on their current methods used for decision support and rate map generation.

This software and the above description of the agronomic-specific knowledge is work beyond the scope of this project.

GIS Principles

For the purposes of an adequate graphical representation of project results and for the spatial manipulations of the data, *Geographical Information Systems* (GIS) software is a well recommended option. For this purpose, a series of GIS courses were undertaken at UCT using their GIS package, Arc/Info.

Geographical information Systems (GIS) has received much attention in the field of agronomy for its versatility, presentation and analytical features in handling spatial data and developing customized maps and data. This type of facility is required for the complex analysis of the data obtained by the yield analysis and soil sampling phases. This analysis can produce outputs representing fertilizer recommendations to be used by the applicator.

The process of the complex analysis of data can be done by various means, but GIS offers many advantages over many of the conventional techniques. The manipulation of the data in a GIS takes place on databases and the resulting fertilizer application rates will probably be in the form of a database/look-up table. For this project, it will be assumed that the recommendations of these rates will be in this form as it would be if it was the output of a GIS analysis procedure.

GIS is a software package which has been specifically tailored to manage data of a spatial nature. 'Coverages' are digitized for a specific area and contain a specific type of information. This information is stored with its spatial attributes in database files. Each coverage therefore also has tabulated/database information linked to it. Each coverage of the same area serves as a layer of information. The information could be soil types, plot areas, roads, relief or chemical concentrations. In fact any type of information can be digitized and can be assigned to a polygon, line or point in the coverage.

GIS also has features which will allow the information in any of the coverages to be displayed in different formats (E.g.: three dimensionally or in profiles), to manipulate the databases linked with the coverages for analysis purposes or to overlay the coverages with the various types of information so that the information has a spatial relationship to the other types of information. The analysis and manipulation of the coverages takes on the form of conventional database

operations with all their available features. Through this, for example, intersections of areas that conform to some boolean criterion could be displayed and manipulated.

Arc/Info is the package of GIS that is available at UCT and consists of various modules which can be used to edit, plot or manipulate the coverages in the desired fashion. The form of the database information conforms with conventional dBase standards.

The foreseeable applications of GIS in this project could be in the graphical representation of the topography of the fields or the soil characteristics throughout the field. It could also be used for the generation of the application rates maps by careful manipulation of the databases based on specified criteria. The advantage of the latter application is that the graphical representation of the data and the spatial relationships of the data still exist and are observable. Other information relating to the operation of any phase of the project could also be calculated from a coverage's data (the instantaneous gradient vector at any one position in the field for example).

Most institutions in the USA implement GIS for the processing requirements of site specific farming. GIS packages such as GRASS and AgInfo which are public domain type applications (developed again as a result of a NASA 'spinoff') are being implemented. Some institutions have attempted to develop smaller packages based upon the GIS principle of handling spatial data but that will run faster and will be more 'farmer friendly'. Texas A&M has developed PC Maps for this purpose and people at Illinois are updating their equivalent package for the possible inclusion of expert systems for the fertilizer application rate map determinations.

Yield-Soil Correlations

Buchholz et.al. [11] applied chemicals simply where they were deficient. No mathematical correlations of the chemical variations of the soil and the yield results were taken into consideration in developing this application strategy. As there were high yield variances in this case, it was assumed that the chemical variances were the cause of the spatially variable yield. The success of this strategy may not be as noticeable if the variances are less pronounced or in another field with different physical or environmental characteristics. It is therefore proposed that the yield results are correlated with the chemical variances in order to establish the extent of the yield dependencies on these factors.

These correlations could simply imply an investigation into high yielding and low yielding *regions* within a field to ascertain the cause of the disparities.

The research described in [10] could result in a far more rigorous approach to correlation analysis. The research indicates an attempt to predict crop yield by means of a deterministic model, the results of which are a function of a complex soil-water-atmosphere-plant complex. More significantly to this project, however, is that it is also hoped that this research will provide an idea of which parameters' variability has the largest impact on the variability of the resulting crop. Such knowledge would provide valuable insight as to what the correlation results might be. For example, if soil tests indicate that the hydrographics of the area have the most significant effect on the yield variances, then high hydrographic variances in the field should indicate the obsolescence of applying fertilizer spatially variably. Similarly, dependencies on the effects of various chemicals could be established. Weighting the variances of the different contributory parameters accordingly could provide an alternate measure of the expected correlation results. It should also provide valuable insight for the agronomists in determining from a first glance at the results of field tests whether the implementation of the service will hold any benefit. Numerical cut-off levels (similar to correlation percentages) could be established at which the use of the service is to be implemented or not. For this reason, it is recommended that the trend of this research be followed up on for future insight into the correlation results. This would also simplify decision making and result in improved innovation in potential farming principles.

Whilst researching the spatially variable application project, the research of [19] was chanced upon and may offer more insight into the correlation problem (i.e. if the other correlation procedures are tedious or are not producing favourable results). The research depicted techniques which could be used for the removal of spatially variable trends within soils. The literature was aimed at establishing the effects of various treatments on soils. The experimentation required analysis on homogeneous soils in order to achieve satisfactory results. Soils are, of course, very seldom homogeneous, and techniques were developed for the removal of the soil variations. These techniques could have application here. They could be used to determine the respective effects of the various yield affecting parameters. This could be achieved through a correlation analysis taken after certain parameter's spatial variability have been removed. This will again produce the same results as was previously proposed using the results of the research described in [10] above. A similar approach (parameter weighting) can be adopted by the removal of all but one trend and the correlation of its effect on the yield.

Grid Size Determination

Field grid mapping, or the establishment of management cells, can be done through the determination of the smallest grid size in which the application rate

could be varied. Alternatively, the field could be grided more generally based upon apparently obvious differences in field characteristics.

The smallest possible grid size is determined by the yield phase as the harvester will most likely have a smaller boom-width than the fertilizer applicator. In the yield analysis of the field, the processing of the yield information is done on a *physical* grid cell size of say 5 by 5 meters which is the smallest grid size possible with a header (boom-width) length of 5 meters.

The grid size may need to be altered if, for any reason, no positioning information is available at certain positions in the field. Efforts can be made to use extrapolation and dead reckoning techniques to obtain position information in such eventualities or in fact whenever there are obvious errors in the position information. If these results are still subject to uncertainty then the strategy described in [4] could be implemented. This technique is to obtain yield information for the entire field by increasing the grid size and averaging the information within the grid area. Grid sizes were increased up to 50 by 50 meters in this case to achieve satisfactory results.

If the data is not corrupted, then a change of the grid size in the yield map may be required due to the variability within the field or because it is desired that a specified number of samples be averaged in each grid square. It should be noted that the choice of yield ranges used in the graphical representation of the information will largely effect the perception of the field variances and should be suitably chosen.

Averaging and Interpolations

This field grid containing cells of information relating to the field could be called a grid of management cells. Each management cell is the smallest area of land to which the system will be able to respond. The size of the cell determines the management resolution. The information attributed to each cell is determined by the average of the punctuated data occurring in that cell. In cases where the management resolution is higher than that of the resolution of the punctual data, an interpolation technique needs to be employed. In this project this could have application to either the yield, soil or positioning information due to areas without information or information with insufficient resolutions.

Various interpolation techniques exist and are feasible for the interpolations of yield data and soil sampled data. Classical statistics can be implemented in the event of *randomly distributed* punctuated data. This usually implies the interpolation of values through the minimization of the mean square errors or a similar technique. Geostatistical techniques assumes the punctuated data is

spatially correlated. Specifically, the Kriging technique uses the punctuated data to determine the value of an interpolated point through an optimal weighted sum of the surrounding points and the minimization of the variances of the data to a spatial distribution or ‘semivariogram’ (see [22]). The use of semivariograms for determination of the SV of pH is described in [42]. This paper deals with the investigation of the impact of further manipulations of the data estimators on the efficiency of the Kriging technique.

Cokriging is another interpolation technique which has application in the event that a certain parameter is difficult to measure or that samples are discarded due to bad laboratory procedure. The technique is useable when one parameter has a strong cross semi-variance (cross spatial correlation) to another parameter.

It may be noted, however, that an accurate interpolation technique may be wasted on data which is subject to fairly high inaccuracies making the elaborate processing techniques obsolete.

2.2 The Positioning Technique

According to the project definition, each phase of the project requires positioning information for the required spatial referencing. This section first deals with the concept of whether the *automatic* distribution of fertilizer over the field is justified. Various positioning techniques for the automatic distribution of fertilizer will be discussed. The most likely technique (GPS) is described in detail in Appendix B, but a few essential definitions are extracted from that appendix without full explanation.

2.2.1 The Feasibility of Automatic vs Manual Spatially Variable Distribution

The manual distribution of fertilizer at variable rates would require the operator to simultaneously guide the vehicle and make changes to the fertilizer rate controller’s setpoints. To achieve the benefit of spatially distributed fertilizers, application maps with 10m by 10m management grid cell sizes, would be a conservative requirement. If the applicator was travelling at a mere 10 km/h (2.78 m/s) and a rate change was required for each management zone, then the operator would be required to alter the setpoint every 3.5 seconds or so. Such a technique would not only make the guidance of the vehicle very difficult but the inaccuracies associated with estimating when new zones have been entered or compensating for the system’s time constants would be inadequate. In conclu-

sion it would appear as if automatic variable distribution of the fertilizer is a vital requirement for the success of a spatially variable agricultural application.

In the system developed in Montana, the location information was converted from radian measures to metres in the context of the field in question and stored on disk for possible post processing. It was also suggested that other spatial information could be collected and added to the database whilst performing any of the tasks involved in the implementation of the spatially variable solution.

Further automation could include the development of an automatic steering system. This would almost make the role of the operator completely obsolete as only the initial positioning of the vehicle and overseeing of its operation would be required. At present the operator guides the vehicle by eye, lining the vehicle up with foam markers in the case of fertilizer distribution for example. The occurrence of fertilizer overlays and skips due to inaccurate vehicle guidance could result in a 10% increase in fertilizer costs or yield losses. The development of such a system therefore has advantages, but increases the complexity of the project considerably. Another point to mention is the fact that the location sensor may not be accurate enough for the implementation of such an extension to the basic function of the positioning system. An alternative could be to develop an automatic guidance system to assist the operator in guiding the vehicle. In this case the human element of whether such a device will in fact be utilized by the operator should be considered in evaluating the use of such an extension to the project.

To discuss the possibility of automatic steering in more detail, the following should be noted:

Previous systems have proposed an automatic steering system that had suitable interlocking features so as to shut down or override at the correct times. The system would operate as a function of directional changes made based on the previous two position fixes and a projected fix. The projected fix could be determined from a steering angle detector and corrections to this projected fix would then be made as the vehicle moves over the field. The desired directional changes calculated from these corrected position fixes would operate a power steering feedback configuration. Automated navigation of this kind, has different accuracy constraints depending on the application for which the automation is required.

Accuracies in automated guidance of about one meter is required for the purposes of taking soil samples in the right place. Alternatively, automatic *vehicle* steering would require positioning accuracies of about 10 cm in the application of preventing skips and overlays in chemical distribution. In the past, real time dGPS implementation would not have been able to cope with these requirements.

The impracticality of this would probably indicate the need for additional dead reckoning positioning.

The control of the *implements* themselves using the positioning information is another option. This has been proposed because of the need to isolate the uncontrollable drifting of the tractor from affecting the implement guidance. This has special application for precision hoeing and ploughing. A positioning accuracy of about 1 cm would be required for the automated guidance and control of these implements.

2.2.2 The Feasibility of Various Positioning Techniques

This section describes various positioning techniques suitable for ground-based navigation or positioning. The relevant techniques will receive merit based on their performance in accuracy, reliability, system compatibility, cost and independence of terrain.

Three systems are considered:

‘Dead reckoning’ is a technique where positions are calculated by means of directions and distances from an accurately known starting position in the field. This technique is cheap and reliable but loses accuracy with time as inherent errors are cumulative. One of the major difficulties with this technique is wheel slip and direction resolutions.

This technique could have a possible application in the event of controlled traffic lanes where the general movements of the vehicle is fairly well established. This technique is especially useless if, as in the case of contoured farm fields, the path of a vehicle is not a simple series of parallel lines but spiral from the perimeter to the centre of the field contour.

‘Radio wave triangulation’ or ‘radio-location’ is accurate, reliable and moderate in cost but is quite highly dependent on terrain. This technique is represented in Figure 2.1.

Radio signals operate effectively through dust and obstructions. The determination of a position through angle location data is not satisfactorily accurate. The preferable technique is to measure position through range measurement.

The range measuring technique usually incorporates time or phase measurements and is based on a geometric principle (usually triangulation). The signals and technologies employed include radio (described above), microwave, radar or satellite.

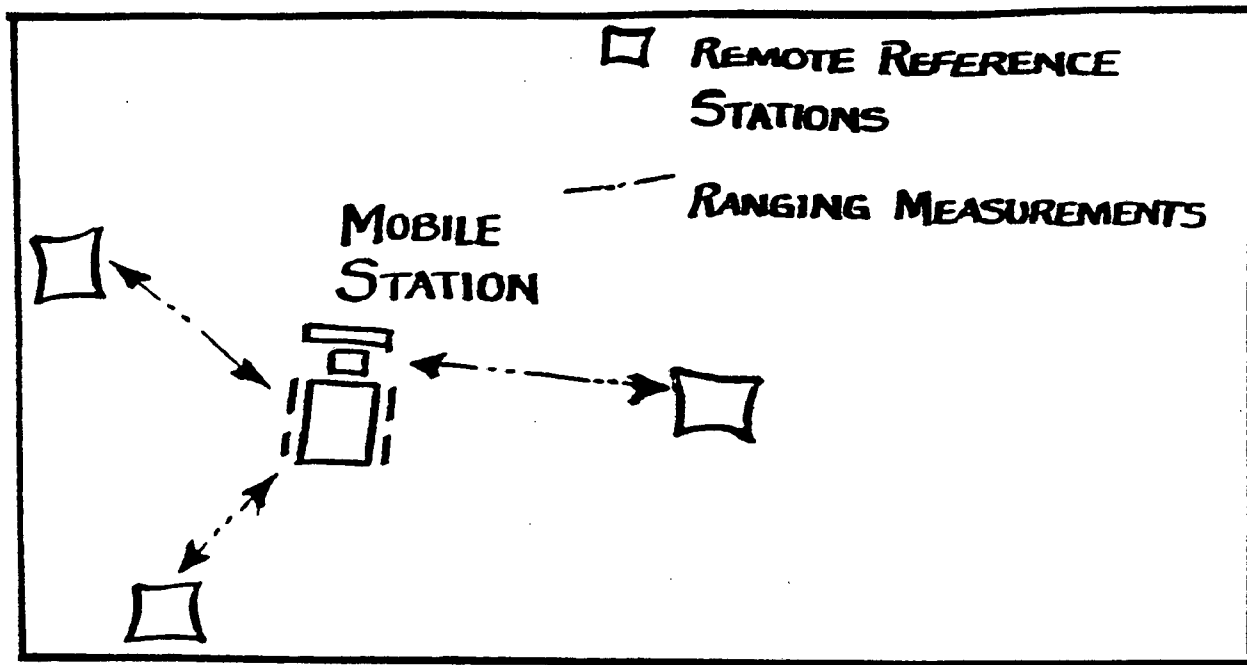


Figure 2.1: Radio Wave Triangulation Principles

For example, a so called 'tellurometer' system¹ uses this technique as does the hydrographic surveying system 'Decca'. The technique is based on the same principle as that used in hydrographic surveying in that the 'surveyor' is mobile. In our case, the catch is that each position in the field will need to be visible to all three remote sites (three high sites on the farm at which the remote stations are placed for distancing information). This system can become expensive when Line Of Site (LOS) repeaters are necessary for these remote sites. A practical consideration is that the 'tellurometer' system requires power to be supplied to all the remote sites, the receiver and the repeaters (batteries operate only for a short while as this is a radar system actually using microwave energy but employing the 'radio-location' ranging/positioning technique).

The tellurometer has remote sites which are portable and about the size of a PC monitor whereas the receiver is about the size of a PC. The remote sites have to have their positions accurately surveyed for each farm using this service. Additional terrain dependent difficulties are that the signals will be subject to diffraction losses, multipath errors and attenuations due to the topography of the land. Although measuring phase differences allows for very small bandwidths and low power consumption, there are difficulties associated with a *mobile* vehicle in that 'cycle slipping' can occur. Cycle slipping is the phenomenon in which the cycle integration reference is lost due to the loss of contact with the remote

¹The trademark 'tellurometer' was initiated by Plessey Electronics

stations thus corrupting the information.

It is worth noting that there are a few other variations in phase measuring techniques employed. The velocity of the vehicle could become a problem when a set of phase measurements need to be taken. There are also inconsistent phase delays associated with the transmitters and receivers which have to be compensated for. A typical price for such a system would be in the region of R185,000,00.

Despite these limitations, much success has been achieved in modern 'tellurometer' systems. Plessey's MRD4 tellurometer system, proposed to have been completed by the end of 1992, is one such system in which most of the range measuring (ground based) technique's difficulties are overcome. With this system, 10 cm accuracies are proposed on a range up to 50 km, the receiver size has been reduced to about half the size of a PC, the remote stations power consumption has been reduced to 15W despite the fact that microwave signals are being generated and a reduction in the cost of the unit has been forecast. These systems would be able to handle dynamic applications and up to six mobile users which could time-share the ranging signals without any loss in accuracy (i.e. time-sharing is required with 'active receivers' needing to transmit as well as receive data). Passive (radar) receivers would allow simultaneous readings on all mobiles and reduce the cost for each user of the technology. Unfortunately, the passive application would prevent real time positioning information.

These systems achieve these accuracies by making phase difference measurements at a series of stepped frequencies. This requires careful synchronization of all the unit's clocks in a system where all the units are transmitting and receiving microwave energy.

Altitude measurements could be provided with this system by implementing a differential barometer configuration (between the mobiles and receivers) if it were required.

'Global Positioning Systems (GPS)' is becoming competitive in cost whilst being fairly accurate and almost completely independent of terrain. GPS also determines positioning information by means of the range measuring principle.

Some of the following technical terms are fully explained in Appendix B but are mentioned superficially here for the purpose of comparing GPS with the other positioning techniques.

The accuracy of GPS has improved since the full satellite constellation has been deployed and with improvements in electronics technology and software development. The accuracies of GPS measurements using single receivers will always be dependent on the amount of Selective Availability (SA) implemented by the US Department of Defence. Differential GPS (dGPS) is meant to be independent of

the level of SA employed, although this is based on the tests carried out on the current levels of SA on a few of the Block 2 satellites only.

In using differential GPS (dGPS) the use of a reference station in addition to the receivers has the same limitations as having to use one remote station in the 'tellurometer' system. i.e. A LOS link is required from the reference station to the receiver for real time information. A far larger area can be covered however, as the reference station can access positions in a full 360 degree radius and can therefore be placed at a more central high site on the farm. This is as opposed to the three high sites surrounding the farm required by radio-location techniques. The powering considerations need only be applicable to this one reference station and are far less limiting as only VHF or UHF radio energy is used. The dGPS system has only one reference station which is portable and requires one surveyed reference position. The mobile receiver is far smaller than that of the 'tellurometer' system making it more suitable for its installation on a farming vehicle. In this application the dependence on terrain is greatly reduced due to the more central positioning of the reference station. In addition to this, the diffraction errors introduced due to terrain limitations will only affect the correction data from the remote reference station and not the raw signals from the satellites required for positioning information.

Actually, other positioning techniques are hardly even a consideration for site specific farming anymore (although implemented in some cases due to lack of funds). GPS has become much more affordable, reliable and accurate over the past few years. A 'GPS User Group' conference held in February 1994 in Cape Town, served to update us as to the extent of the genius of the civilian user. It is now possible, through clever algorithms, to implement surveying GPS techniques in 'on-the-fly' applications. Therefore, dGPS can provide positioning accuracies to 20cm or so in real time dynamic applications. It is no longer necessary to maintain your baseline and survey positions statically as required of the old surveying techniques. This would greatly improve the possibility of accurate fertilizer placement and provide the potential for dGPS use in automatic steering and implement guidance.

Although dGPS has been claimed as being a great technology, there are a few associated warnings. Many manufactures claim their ability to provide enhanced dGPS capabilities, when in fact they are actually only advertising the feasibility of it and not the existence of such systems. A few systems have however been developed and have been effectively implemented. It may be worth noting that the problem of multipath errors has not been completely removed from the satellite signals in GPS due to the presence of nearby vertical obstacles (forests etc.). Such obstructions could also result in the positioning information being lost at times.

A cost of less than R100.000,00 is not uncommon for a good differential GPS system. (i.e. including the Data Transmission Link (DTL) and the data capturing equipment).

'Proximity systems' is another type of positioning technique using physical markers or in fact transmitting from a permanent location. Laser distance measuring meters have excellent accuracies but have not yet found suitable application in agricultural systems. It would make sense that apart from the usual line of sight limitations, it would be difficult to orientate laser equipment effectively on an agricultural vehicle.

The contending positioning systems are becoming predictable in their trends with regard to their performance and cost. GPS is now marginally less accurate but more cost effective. According to this argument it is apparent that GPS will continue to become more affordable and more accurate whilst radio location systems will always be limited by their terrain dependencies no matter how advanced the technology becomes in overcoming the inherent difficulties associated with the technology. The crux of the argument are these budget, positioning accuracies and reliability requirements.

DGPS has been successfully implemented in other systems ([28], [8] and [30]). In these systems dGPS has been implemented as a precise positioning system to be used for the application of crop inputs exactly where they are required. In addition to this, dGPS has also found its application as an operator guide. This further substantiates its applicability to this project implementation.

It was also noted in the literature that dead reckoning is often used as a backup positioning technique in the event of corrupted positioning information.

2.2.3 GPS Principles

This section will outline some of the essential GPS definitions.

GPS works on the principle of range measurement from a receiver on the surface of the earth to a number of satellites above the horizon at the time of measurement. The satellite constellation and orbiting characteristics are such that it be suitable for the determination of the position of the receiver continuously and at any position on the globe. The tri-lateration of the calculated ranges to the satellites, is known as the pseudo ranging technique.

The principle is based on the assumption that the receiver knows two things. The first is each satellite's position, which is obtained by means of a navigational message transmitted by the satellites themselves. The second is the satellite's clock

interval. This latter knowledge should allow the receiver clock to generate the modulating code synchronously with the satellite's clocks for matching purposes. The navigational message contains information on when, in real time, the code was actually transmitted by the satellite and this allows the receiver to correct its synchronicity with the satellite clocks.

GPS determines receiver positions in the World Geodetic System (WGS84) which specifies the world datum, ellipsoidal or geodetic co-ordinate system and gravitational model to be used.

Four satellites are required to be visible above the horizon at any one time. This is in order that the four variables of the 3 dimensional position and the time difference between the synchronized satellite clocks and the receiver clock can be determined.

The satellites themselves transmit two frequencies L_1 at $154 * f_o$ and L_2 at $120 * f_o$ where f_o is 10.23 MHz. Either or both of these signals can be modulated with the Course Acquisition (C/A) or Protected (P) codes and the navigational message.

The US Dept. of Defence (US DoD) have instituted two levels of system implementation. The Standard Positioning Service (SPS) is primarily designed for use by the civilian user. It uses the C/A code and makes only one of the two carrier frequencies available for modulation. This makes it more difficult for the removal of ionosphere errors. This service provided positioning information more accurately than the designed specifications and as a result, the US DoD introduced the 'selective availability' (SA) policy. This policy was to downgrade the system by placing a jitter on the satellite clock information and a coded bias on the satellite ephemeris parameters to which the US DoD has the 'key'. With SA a positioning accuracy of 50m (1σ) is possible but is entirely dependent on the level of SA.

The other level of implementation is called the Precise Positioning Service (PPS) used only by the US military and makes use of the P-code modulating two carrier frequencies and is capable of a positioning accuracy of 10m (1σ).

If there are more than 4 viewable satellites, then the method of least squares is used to solve the over-determined solution of the set of equations obtained from all the satellites in view:

$$X = (A^T P A)^{-1} . A^T P I \quad (2.1)$$

Where X is the solution vector of the 3 dimensional positions and the time offset term, A and I were determined from the set of pseudo range equations for the

satellites in view such that $A.X = I$ (See [21] for details of the elements of these matrices). P is a weight matrix (usually diagonal), weighting all observations equally.

An estimate of the suitability of the geometry of the position 'fix' can be determined from this least squares solution. This quantity is called the Dilution of Precision (DOP) and is described in [21] in more detail.

Now the calculation GDOP (Geometric DOP) is determined by:

$$DOP = \sqrt{Tr(N^{-1})} \quad (2.2)$$

Where N is the matrix $(A^T P A)^{-1}$ in the above equation. The PDOP (Position DOP) is determined from the Equation 2.2 but excludes the fourth time offset term. PDOP is therefore determined from all the satellites in view.

Differential GPS is illustrated in Figure 2.2. The reference station (GPS receiver) is placed at a surveyed position and calculates corrections for the position generated from the satellite information. These corrections are used to alter the readings made by the GPS receiver at the mobile station. DGPS helps to overcome many of the errors associated with stand alone GPS operation, including ionosphere errors and SA. For real time dGPS accuracies a Data Transmission Link (DTL) can be used to transmit the corrections to the mobile receiver.

2.3 Assessing and Compensating for Soil Spatial Variability

The feasibility of this project was investigated based on other implementations in other countries. Previous developments in compensating for soil spatial variability were also investigated to establish which techniques were implemented. This included those methods of sensing, interfacing, processing and controlling required by the various phases of the project. It was hoped that this would indicate which techniques are most efficient and fundamental to a SVFAP.

2.3.1 The Feasibility of a SVFAP

As part of the literature review of the project, the feasibility of the SVFAP was addressed. This was evident through the results, interest and investment into similar projects.

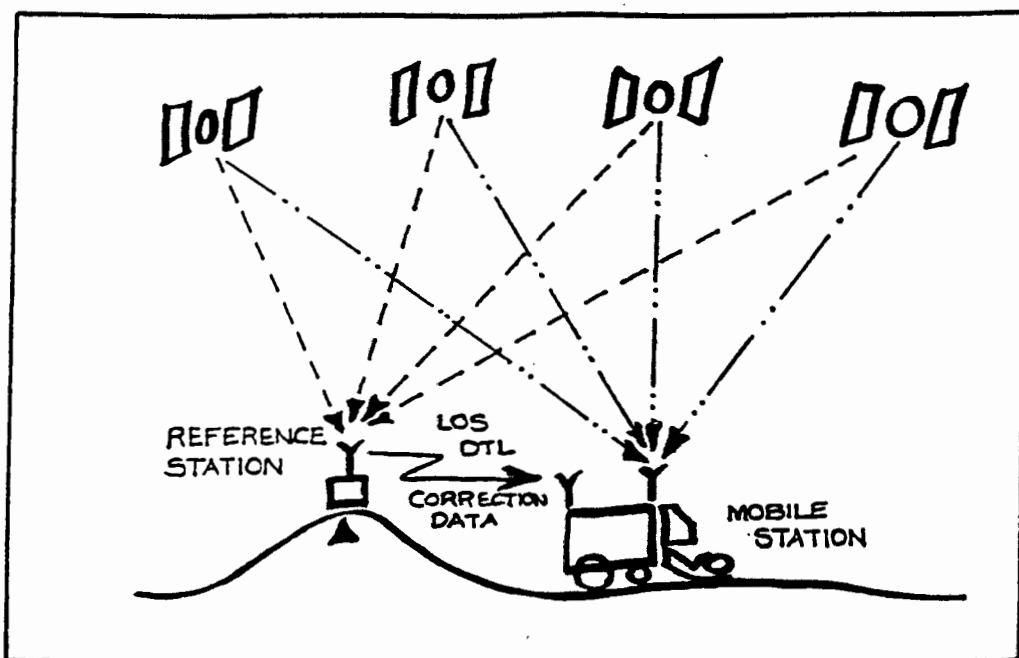


Figure 2.2: DGPS Principles

There are two main motivations for developing agricultural systems that operate spatially within fields. The first is due to the expected increase in crop yield due to the more efficient use of agricultural chemicals. The cost of developing such a system is, however, fairly expensive (especially for a small farming concern) and the system would take a time before it would pay for itself. The major advantage of such a system would be the environmental benefits. Investigations have shown that about 36% of the phosphorous and 42% of the nitrogen found in surface waters are coming from agricultural applications. The associated negative effects of other chemicals and pesticides have also been well established. Implementing this technology successfully could result in less residual nitrogen in the soil after harvesting and therefore substantially reduce the leaching of this and other chemicals into the groundwater.

Descriptions of the various activities within site specific farming indicates the feasibility and popularity of spatially variable agriculture.

Various references to companies and institutions involved in spatially variable agriculture were indicated in [32]. It is noted that even at the date of publication of this article, a few companies had already produced commercially available SV applicators. This literature is filled with references testifying to the developments and interest within this field.

A recent on-line literature search indicated that *current* research includes the

following:

- 'Sensing and control technology to optimize cropping system inputs' undertaken at the Agricultural Research Service in Columbia, Missouri.
- 'Engineering systems for spatially variable agricultural production' undertaken by the Texas A&M University in Texas.

The system developed by the Precision Land and Climate Evaluation Systems (PLACES) group at Montana State University indicates a successful implementation of differential Global Positioning Systems (dGPS) in fertilizer application and is described in [28].

It is predicted that this technology would not be a feasible option for individual growers to buy unless they had a suitably large concern. The reasons for this is that the equipment would only be used once per harvest and the predicted profits from the implementation of the service would only be likely to pay for the hardware after a few harvests. Such a service would be ideal for a concern which dealt mainly in hiring out the expertise and equipment to the farmers. Input suppliers or farming co-operatives may fall into this category.

The successful results of variable application of lime, potash and phosphorous on a 2 to 4 acre grid based on soil surveys for phosphorous and potassium are presented in [11]. In this case success was achieved despite the fact that the soil was chemically surveyed assuming homogeneous soil properties throughout the field, i.e. fertilizers were applied to the field based on the results of the chemical survey only and no yield correlations were calculated. Taking the other aspects of soil variability into account when making fertilizer recommendations will only improve the results.

The positive results indicated in [11] are an excellent indication of the feasibility of the technology as the techniques employed were extremely makeshift and the performance of a more accurate strategy could only improve. Another farmer using soil maps and grid soil testing for increased nutrient precision use on his farm, indicated a \$14 increase per acre taking improvements in fertilizer, seed and chemical use into account.

One case in particular is encouraging for the cause of site specific farming. A farmer in Missouri has conducted detailed soil tests of 10,500 acres of farmers' lands and offers this information as a service. The testing of the soil was done on 2 $\frac{1}{2}$ acre square grids. This information is being used in conjunction with machinery which can read the generated soil fertility map and is capable of blending and spreading up to 6 dry inputs at a time.

As an indication of the interest generated by this technology, it is worthwhile stating some of the institutions which have committed themselves to it. The computerization operating on the above machinery in Missouri was patented by Soil Tec Inc. of Waconia Minn. and costs from \$100,000 to \$170,000. Applying this fertilizer with this specialized machinery has been estimated as running at about \$6.50 per acre. Most of the machinery is owned by farming co-operatives or farm supply dealers and offer the service at a flat rate. A Kansas co-op. charges \$7.55 per acre for a field to be sampled and mapped. Various other departments, councils, services and universities in Missouri have helped reduce the cost of mapping an acre of land from \$9 to \$2. There are various co-ops in Advance and Charleston who are feeding capital into the Missouri farmer's project.

In one example, the farmer applied the system to 700 acres planted to corn. A 20 % savings on inputs (approximately \$5000 worth) was estimated. One 170 acre field required phosphate application ranging from 0 to 85 pounds per acre and potash from 20 to 70 pounds per acre. These figures are in contrast to the respective 40 and 100 pounds per acre which would normally have been uniformly and respectively applied without this technology. Some fields did not, however, show enough variation to warrant the cost of sampling. One ag-chemical manager says that soil sampling and mapping need only be carried out once every three years in some cases. All the above figures were valid at the time of publication of the accompanying literature [18].

It was also noted that there still exists some skepticism with regard to prescription farming. A certain soil scientist quoted that he believed that it will still be profitable to fertilize fields uniformly. This is said with reference to the fact that these applications have found their greatest usefulness in areas where the soil types vary widely and on irrigated so-called high dollar crops such as corn, potatoes and sugar beets.

The case described in [12] provides a warning for the implementation of *optimum* fertilizer treatment based on expert agronomic input. In this case returns were \$2.06 and \$5.14 greater per acre for spatially variable treatment as opposed to uniform field treatments in three of five fields tested. Overall however, returns were not substantially large. It became apparent that recommended fertilizer treatments were not always optimal treatments as two fields produced returns of \$21.68 and \$23.51 per acre when more optimum and precise treatments were applied. The conclusion is that accurate soil testing and reliable fertilizer recommendations are essential in the development of a suitable strategy for generating greater returns through spatially variable agriculture.

The extent of the interest in site specific farming was most apparent at the American Society of Agricultural Engineers' Winter Meeting in Chicago in 1993. Based upon the representation by universities, agronomic extension facilities as well as

equipment manufacturers at the conference, it would be fair to say that Site Specific Farming is alive and well in the US. Every university with an Agricultural Engineering Faculty in the USA appears to have some involvement with some aspect of the technology. In most cases however, you would find a group of researchers working in detail on some aspect of the SVFAP. For example, yield map generation and GIS work is an emphasis at the University of Missouri. Groups who have managed to test the sequence of procedures to get some real results on actual yields, have had to rustle up a rustic system to carry out the various phases of the project (see [29]). Slowly the tools to implement the various phases (application technology for example) are being developed.

General interest journal articles describing Prescription Farming are typical in at least one such journal every publishing cycle. Even NASA, in its efforts to remove the military emphasis and find other commercial applications for their facilities, has become involved. Entire workshops and conferences are dedicated to Site Specific Farming.

The motivation for the interest is still twofold; for increased yield and the associated environmental benefits. A great deal of the work in the USA is being done by organizations dedicated to improving ground water quality. The agenda described by the University of Missouri's extension facility is an example of this.

2.3.2 Previous Developments

The aim of this section of the investigation is to establish what developments have taken place in similar projects to our own (i.e. for the development of a SVFAP). The emphasis here, is more on the hardware developments to illustrate a potential hardware solution.

GPS, GIS, Remote Sensing and Other Ideas

In [4], the use of dGPS is recommended for the positioning requirements of the service. A further proposal is for the formulation of weed maps also during the harvesting phase. This could be achieved through carefully sieving the cereal produce with an image analysis facility on the weed mound. Some of the recommended sensors to be used in the *measurement of the yield* are a paddle-wheel (level sensing type) or x-ray sensor for yield indications on a cereal harvest or strain guages or load cells on a straw harvest. The distribution of the liquid chemicals could be achieved through a hydraulically driven positive displacement pump and slip control. Other recommendations were made for the application of mineral fertilizers.

The use of *dGPS* for the georeferencing (the determination of ground control points or GCP's) of remotely sensed images for their inclusion in a GIS system or in fact for the development of maps, was investigated in [27]. This article describes some of the applications of remote sensing to site specific farming and the use of GPS technology for georeferencing images requiring real time positioning information. The accuracy of the use of GPS in this application was determined by comparison to topographical maps and other orthophoto maps previously determined. The results indicate that with post processing, dGPS technology could be used to determine GCP's with an accuracy comparable to or better than points digitized from 1:24000 scale maps. This would be especially useful if *remote sensing* was to be used for agronomic data.

For a more thorough research into the origin of spatially variable application, [32] provides the references needed to obtain an insight into the developments that have taken place within this field.

Regarding locators it is indicated that triangulation techniques have been implemented in the past but that the line of sight restrictions have been a limitation. Dead reckoning has also been implemented as a locator for agricultural purposes. This was because the use of GPS at the time of publication of this information was not considered a feasible option. At the time, the lack of available satellites and technology to deal with the selective availability constraints were too limiting.

With regard to remote sensing and aircraft measurements, the article described their possible relevance to this application but could not add to the limitations described in the Section 2.1.1 of this literature review. The possibility of making infrared measurements whilst undergoing other field activities was also discussed and may be of interest to the agronomists. The most relevant results are those pertaining to the sensing of organic matter.

The generation of accurate topographical maps seems to be proposed with the use of a laser levelling mast.

The use of GIS in the storage and manipulation of spatially variable data is recommended and its level of suitability is discussed. The relevance of agricultural models simulating plant growth similar to that discussed in this literature review (see Section 2.1.2), is noted as having application in the development of a management strategy for the distribution of fertilizer. The resulting application maps need to be adjusted to compensate for the dynamics of the controller as in the case of the adjustment of the harvester readings.

With regard to controllers, various dry and liquid fertilizer controllers have been developed for application purposes. The relevance of this research to other agri-

cultural concerns, such as pesticide application and planting, was again stressed. A unique concept for consideration, is for site specific tillage using automated laser levelling for topography detection. The automatic or temporally separate implementation of this technology could be decided upon depending on the limitations of the technology.

Real Time Sensors

Research is being carried out in the field of real time sensors and some of the results are described in [43] and [37]. The significant developments appear to be in the fields of nitrogen and organic matter level sensing.

Real time nitrogen sensors involve preparing a sample in a solution and taking a reading of the electrical signal generated by the soil-solvent reaction. The challenge is to achieve this on a moving application rig and adjust the application rates accordingly. This has been achieved and there are even more developments in which very rapid and accurate readings can be obtained using ion sensitive field effect transistors as sensors. Another predicted development is in measuring the soil electrical impedance in a 'dry' sample.

Great success has been achieved in Organic Matter Sensing using an infrared reflectance-based meter and is described in some of the papers received. This is currently being used in conjunction with spatially variable herbicide application to ensure automatic application of herbicides on the go. An organic matter probe is based on determining the colour of the soil. Organic matter sensing can also be used for yield comparisons at harvest. This sensing is, however, sensitive to moisture levels in the soil and has resulted in efforts to simultaneously develop soil moisture level sensing on-the-go. It has been found that using near infrared reflectance, both the organic matter levels and the moisture content can be determined [43].

Another automatic application achieving a spatially variable function is in the sprayer-mounted cameras used to detect various weed species.

Other efforts are being made in the fields of pH sensing and soil textures. This data can be used in conjunction with soil moisture to help fine tune organic matter readings and adjust crop protection product and herbicide application. Soil texture determines water holding capacity and can therefore assist variable irrigation schemes.

There are various other field diagnostic kits available. They are not real time sensors and require a certain amount of soil preparation. These kits can effectively detect pH and nitrate levels as well as infer sodium and potassium levels. This

is done by performing small experiments in the field in which it takes about 5 minutes to prepare the sample. Similar moisture probes are available for field testing.

The Applicator Phase

Solutions for an *applicator phase* of the project have been developed and one such example is described in [37]. As is the case in our application, the criteria for the development of this project were cost, accuracy, range, commercial acceptance and practicality. The difference in our context is that available technology is also a consideration. Apart from the ability to be able to vary application rates, this system was also required to record the chemical applications and possibly also the localized field conditions. This work described the advantage of controlled traffic farming in which the vehicles are required to drive upon established traffic lanes. There are agronomic as well as managerial benefits associated with this strategy. Controlled traffic farming was in fact, a necessity in this case, as a dead reckoning positioning system was used for the positioning requirements. Another point made, was in the need for advance control on the applicator due to the inherent delays and time constants of the applicator.

The description of this applicator system indicated a need for establishing the requirements of the hardware solution and a step by step description of the system operation. For example, one of the hardware requirements is the ease of hook up of the various sensors and peripheral components required for the control functions of the project. This would facilitate the portability of the system. In this applicator design, the computer *directly controlled* the device altering the flow of fertilizer via the control of an electric motor. All other interfacing was done through communication to a *control box* via a RS232 serial link. The control box consisted of an analogue to digital signal conditioner and facilitated the buffering required to transmit hardware system signals to the computer. The conditioner could also read and generate digital inputs and outputs. Additional circuits were included in the control box to facilitate the direct monitoring and controlling requirements of the applicator. Some of the system operation procedures included the recording of the path as well as the points at which the application rates change for historical records. The system enabled an audible beep indicating rate changes and allowed for other field observations to be recorded via function keys. Other information such as application rates and distance and position were also displayed on the operator interface. The user program and application map was loaded onto the computer by means of diskette. The field information was then downloaded from the computer memory back to diskette on leaving the field.

Many of the papers at the ASAE Winter Meeting in Chicago had to do with elec-

tronic communication considerations, distributed control systems, other equipment feasibility studies and implement guidance. It appeared as though pneumatic seeders, low volume pesticide and herbicide applicators and spatially variable irrigation systems are commercially available and well suited to variable application.

Notes were taken as to the various recommended nozzles that exist, and literature collected wherever spatially variable fertilizer application had been put into effect (SV Nitrogen application in Idaho for example [29]). In terms of applicators either implementing SV application or that are suited to SV application, some literature was collected. It seems that a liquid injection, variable displacement pump or a variable pressure system is an established technology for low volume applications (herbicides and pesticides) and have good spraying patterns.

In terms of on board blending and fertilizer application, a commercially developed dry fertilizer applicator is available. This applicator is capable of blending different dry chemicals as you move about the field and according to your requirements at each position. Pneumatic as opposed to spinner options are preferred as more uniform spreading patterns result. Liquid fertilizer distribution is more difficult due to the larger volumes involved however spraying patterns are not as much of a serious consideration. Mixing liquid fertilizers on board does not appear to be much of a consideration. What is implemented commercially is the injection of trace elements, pesticides or herbicides together with your dry or liquid fertilizer blend.

The Yield Analysis Phase

An example of a *yield analysis phase* is described in [35]. A combine was instrumented with a portable computer and a data acquisition unit (DAU). DAUs may be required for specialist signal conditioning functions such as A/D conversions and buffering functions. Some signals (the location information for example) were fed directly into the computer without using the DAU. In this application, the header height of the cutting blade from the ground, the engine, combine cylinder, rear feed conveyor speeds as well as the ground speed were detected by the system.

The yield meter used in the above system was the Claydon Yield-o-meter manufactured by Sheldon Reynolds Engineering in England. This meter implemented a paddle wheel configuration for detecting grain flow. The resulting yield measurements were also displayed to the vehicle operator in real time. The yield meter was calibrated and the yield results were simulated to establish the extent of the errors involved due to the discrete nature of the flow meter. Classical dig-

ital filtering techniques could not be applied to remove the errors, as the pulses were not uniformly spaced in time. A weighted third order filtering algorithm using an arithmetic average was employed on the grain flow data.

The power requirements of this system were such that a 3 kw portable gasoline generator was required to supply the computer, data acquisition system and location detection equipment on-board the harvester. The reasons for the high power demands seemed to be in the supplying of the 24V DC supply required by the microwave triangulation positioning technique employed (GPS was not a feasible technology at the time). The remote stations were powered by automotive wet-acid 12V batteries.

The research indicated the need to find the optimal location of the remote stations given the field configuration and environmental constraints. Knowledge of the accuracy of the positioning information was also necessary and in this case the location data was smoothed by taking the average of five data points centered at the point to be smoothed. This averaging technique needs to be carefully established so as not to corrupt the true location information.

It has been established that the grain flow coming out of the filling tank auger is not a true representation of the yield at the current position due to the delay involved in the processing of the grain in the combine. In addition to this, the grain is also distributed in the combine and possibly even recycled making yield reading an inaccurate representation of the yield of another fixed position. It becomes necessary to model the process to account for this.

In [35] it was noted that the physical modelling of the flow of grain is too complex and that a better solution would be to estimate the system as a lumped parameter system. To ensure the zero initial conditions pre-requisite essential for laplace modelling, tests were carried out by driving the harvester into the crop at a constant velocity to simulate a step change in the input. The results seemed to indicate a first order response and so a first order model was used. A more complex model may be required if the first order characteristics are not as pronounced.

It needs to be noted that the test conditions are not perfect. The simulation of the step change is not guaranteed as the crop may be increasing or decreasing and the general observation was that if the crop intensity was changing, it had an effect on the time delay. The noted observation was that the transportation delay had a negative correlation with grain flow rate in the tested range but that the time constant of the model was independent of it. A slower time constant was noted on exiting the crop. In addition, manual crop estimations seemed to indicate higher yields overall but much less yields than indicated in moments of high variability. This does imply that a higher order or more complex model and

testing procedure may be required for accurate results. The manufacturers of the combines also indicated that the recycling effect of the combine gets worse with larger yield variances within the field.

Apart from the relevant filtering and adjustments of position and yield information, it was also necessary to time flag the data in order that a yield map of position-yield pairs could be established. This pairing was achieved through the relevant interpolation and re-sampling of the data. The sampling rate is determined by the average speed of the combine as well as the update rate of the location or yield information, whichever is the slowest.

It is worth noting that the required accuracies of the yield measurements need not be as stringent if the inaccuracies associated with the positioning information are large enough. This makes sense when one considers the assignment of yield values to erroneous positions due to the positioning errors.

To validate the correct functioning of the yield analysis system, expert estimation based on field observations or some manual sampling technique could be employed. Discrepancies can be expected due to the errors in the flow meter and estimated combine model.

Another physically built and tested yield meter found whilst conducting the literature search was documented in [44]. This meter employed a technique whereby the grain from the original grain filling auger was redirected into a pivoted auger, designed to pivot according to the amount of grain filtering through it at any one time. The grain flow is then determined by the control signals generated as a result of the dynamics of the pivot motion. The necessity of determining the time delay in the grain moving from the cutting edge to the auger was again stressed in this literature.

The overall results of the yield measurements were more favourable than those predicted by the paddle wheel configuration. It was noted, however that there was a difficulty in determining the yield in the small plots with the least specific (lowest) yield results. This was predicted by the non-linear nature of the meter not compensated for in the regression model used in the calibration of the meter. As it is difficult to make localized accurate yield measurements (either manually or by other means), no such measurements were made to determine the dynamic response of the yield results to yield variations. If the method of measuring technique is accurate enough, then the interpretation of the results (including the prediction of yields under transient inputs) is dependent on how accurately the system is modelled. Erroneous results could be due to either a bad measuring technique or erroneous interpretation of the results.

Various institutions (Kansas, Idaho and Illinois) had developed their own yield

measuring sensors based upon separate principles of operation. Of these, only the Illinois sensor may be worth further investigation. This was based on level (volume) measurement by means of five photosensors on the elevator auger. There are various sensors commercially available. Two employ a volume measuring principle and one a radiometric principle, the latter of which is highly recommended according to a feasibility study done in Germany (See [3]). The author expressed his concern in the effects of harvester tilting on the accuracy of volume measuring sensors.

Communications and Interfacing

The general communications requirements of a spatially variable agricultural production system is discussed in [38]. This discussion deals with the general communication requirements of all spatially variable agricultural processes and the need for the standardization within the agricultural instrumentation industry. Although the discussion is specifically aimed at all types of systems it still has relevance to our specific implementation of spatially variable farming. It is described that the International Standards Organization (ISO) has established a reference model used in establishing the communication requirements for data communication systems. This is called the Open Systems Inner Connection model (OSI). For a large data communications project, it is required to define and standardize the requirements of the system on the various layers within the reference model.

The literature points out that this system's data communication requirements are unconventional in that there are two communication problems implicit in the same system. The first is the transfer of data from agronomist's databases (in which the desired application rate maps were generated) to the mobile vehicles. This is achieved by a form of memory storage media and also requires standardization. The possibility of programming a device which can be carried to the vehicle ('a sneaker net') was suggested. The second communication problem is at the mobile site where the vehicle must control the flow of data according to the phase (or vehicle) in operation. A 'mobile communications network' may be required to perform several functions simultaneously and therefore implement what is known as a connectionless mode data transfer (or master slave communication on a multidrop network) in which more than one mode can access the information on the network.

In the general case, it is required that the protocols in the data communication system are defined and standardized. In this case the following needs to be defined where applicable:

- Message identifiers

- Data formats
- Format for rate maps
- Format for sample data
- Data storage media
- Mobile communication network

In the implementation of the 'mobile' network, the communication requirements need to be established through the quantification of the following types of messages this system will require.

- Periodic messages
- Control messages
- Data recording messages
- Status messages

A preliminary evaluation of a full spatially variable agricultural production system indicated that a baud rate of about 9600 would be required. Another noted point was that other network considerations such as the transmission error detection and message transmission latency needs to be decided upon. In this case it is noted that transmission latencies of up to 250 ms would be insignificant compared to the time delays associated with location detection, rate table look-up and the time constant of the applicator. A highly reliable error detection facility is however required as erroneous data could have significant repercussions.

For all phases of the SVFAP, the interfacing of the relevant inputs to processor is required. The various techniques of interfacing the inputs to the processor were investigated. The possibilities extend from multiprogrammers and data acquisition units (DAU) to complex distributed computing control networks (DCS). The latter proposal seems a little bit of an over-kill based on the current understanding of the interfacing requirements.

For the purposes of this data acquisition, other specific VXI bus equipment to be placed on HPIL, HPIB or VXI Bus lines was investigated. This was in accordance with the suggestion of implementing a multidrop data communications network at the mobile station. Such elaborate data acquisition may not be required and the use of a simple I/O card read through a serial link may be sufficient for the preliminary solution.

These topics were dealt with in much more detail at the ASAE conference and are representative of the importance of these considerations. For further reading and insight into these ideas see [2], [41] and [45].

Software

In the description of the format of a software package developed for the purposes of the *agronomic analysis* required by this project and described in [39], the procedures and considerations required for the generation of such a software application are described. This can be used as a guideline for the generation of any software package. Apart from the description of the specifications of the software, the reasons for the specific choice of programming language are also outlined and provides a guideline as to what factors need to be considered in the choice. The literature explicitly describes the useful characteristics and virtues of C++ as an object orientated programming (OOP) language. An example is provided of how to specify the structure (classes) of such an OOP application.

Some software has been developed *commercially* by Agricad, for example, which provides a marvelous graphical interface with all the required prompts for system operation and status indication. The system seems to incorporate some of the mapping facilities of GIS with the required interfacing software for operating and providing the interlocks for an *applicator*. Having the GIS facility allows the user to view the database information graphically or implement it in spreadsheet operations. The software also provides sophisticated planning and analysis tools and therefore provides some of the software requirements of the agronomists (similar to that defined in the software developments undertaken by Texas A&M University [38]). The advantages of the system being linked up with the GPS facility is that mapping and data entry can occur almost instantaneously.

Software which can do the necessary processing on the *yield* and positioning information so as to produce yield maps has also been developed for RDS, a UK based company dedicated to providing electronic instrumentation specifically for spatially variable agriculture. This software together with a data transfer facility from a yield meter, has been predicted to handle all of the yield processing requirements. Its implementation in this application will however, fragment the software of the 'black box' system unless it can be incorporated into the system software.

2.3.3 Literature

Many of the references given in this report are for the benefit of those more directly associated with the agronomic world. It is proposed that some of the information would greatly assist these scientists in that it could provide invaluable information for site specific farming and would be better interpreted by them. A summary of these and others are given here under the relevant topics.

POSITION DETERMINATION:

[26], [4], [28], [9]

SAMPLING, SOIL SAMPLERS AND SOIL VARIABILITY:

[22], [12], [42], [25], [39], [11], [18], [32], [23]

REAL TIME SOIL SENSORS:

[13], [43]

YIELD MAP DETERMINATION AND YIELD SENSORS:

[44], [35], [8], [7], [30], [14], [3], [24]

FERTILIZER APPLICATOR DESIGN:

[34], [33], [6], [15], [36], [1], [20], [37], [10], [29]

COMMUNICATIONS AND INTERFACING:

[2], [41], [45]

2.3.4 Some Results

Various institutions have been working on the generation of yield maps (See [8], [7], [24], and [35]). Missouri State University instrumented two harvesters with two different yield sensors and the data acquisition required. In their conditions, they also found it necessary to have moisture measurement and compensation.

Idaho State University implemented the sequence of phases required of the SV-FAP for two seasons (See [29]). It should be noted that they were limited to semi-automated solutions in each of the phases and their fertilizer application was particularly rudimentary.

The application phase has also been undertaken by various parties and is repre-

sented in [6], [27], [33] and [34].

2.4 Equipment and Technology Evaluation

This section deals with the issue of what technology is available to us. Existing equipment and machinery to be used in the various phases of the SVFAP is also investigated.

2.4.1 Positioning Systems

The triangulation positioning system, tradename ‘tellurometer’, is available from Plessey electronics and comes in a number of varieties depending on the performance requirements.

CSIR and Barcom have both manufactured GPS receivers locally but it has proven to be more financially feasible to import the units (from a company like Trimble Navigation or Magnovox). The trends in South Africa are to develop systems utilizing GPS systems for user-specific applications. i.e. Companies like Delcon and Plessey would serve to import the units, utilize them in the desired application and train and support the users.

Various data transmission links in the form of VHF or UHF radio links are available and have been utilized in other projects. Such DTLs are required for the implementation of dGPS.

2.4.2 The Yield Meter

A piece of equipment essential to the temporally separate solution of this project was a continuous yield meter of suitable accuracy. On researching this technology, it became apparent that there has not been much use for such a meter in this country in the past. Combine harvester manufacturers, agricultural departments, agricultural academic institutions and farming product suppliers alike did not have any knowledge of suitable meters. Yield was simply determined as a bulk weighing of the crop after harvesting each field. According to the experts, there were no such meters locally available but they did give their input with regards to a few of the suggested principles to be employed if such a meter was to be patented. Some of these proposed designs were recommended in the literature [4]. Of the proposed solutions, the following were supported:

- A meter employing a differential weight measurement using load cells (possibly in a bucket which is periodically emptied).
- A conveyor principle in which weight measurements are integrated over its length, similar to the kind used in industry.
- A tilted auger suspended by load cells.

All of the above proposals could be implemented using an additional and identical measuring device which could be used as a reference to remove common vibrations on both the measuring mechanisms.

Some literature seemed to indicate that some designs had been implemented for similar projects overseas, but they were not commercially available. Of the commercially available yield flow meters, the only lead was for the possible purchase of a continuous yield meter being developed in the UK specifically for this application. The manufacturers of the meter are RDS Technology Ltd, a UK based company dedicated to providing electronic instrumentation specifically for spatially variable agriculture. This meter was only predicted to become available by the end of 1992 but was still considered to be worth the wait as the development of such a meter is not only out of the scope of this project, but is also a time-consuming endeavors.

Based on some correspondence with the manufacturers, this meter employed a patent which measures yield by means of the light displacement on the intake side of the grain elevator. The meter appeared to be fairly comprehensive, taking many of the measurement's variables and dependencies into account (time delay, header height, combine speed and localized calibration requirements). The retail price of such a unit was estimated at approximately £1,500. Some reading under this topic indicated the need for the modelling of the combine and further adjustments to the readings in post processing (compensation for the combine's time constant for example).

The meter requires the input of bushel weight or h/liter weight as the yield measuring patent actually measures volume. The cost of purchasing and installing the meter is R 11,950.00.

The data transfer system which will be implemented for this application would be to simply connect the interface (RS232) cable directly to the on-board computer. The disks (Ceres' RDSCOM disks) for the logging of the data will probably not be required, as the raw serial data will be used to interface with our software developed for the logging and processing of *all* the foreseeable inputs to the on-board computer.

Software to do the necessary processing on the *yield* and positioning information so as to produce yield maps, has also been developed. This software (Optimix software in this instance) together with a data transfer facility from a yield meter, has been predicted to handle all of the yield processing requirements. This software will not be able to be implemented as it requires location data from RDS's Jupiter Vehicle Location System which has not yet provided them with satisfactory results. As mentioned above, it is also believed that a little more additional processing of the yield meter's readings will be required and this will require specialized software. In addition, the implementation of this software for our purposes will fragment the software of the 'black box' system unless it can be incorporated into the system software.

Using this meter, the smallest resolution of yield data will be on a '10 X header width' meter grid as the meter provides a yield measurement for every 10m of travel.

It is also noted that should the meter not be required for the downloading to a computer, the ICP 100 in-cab printer can be attached to the device to provide a printout of the yield data as you move through the field.

2.4.3 Other Peripherals

A LCD operator interface has also been developed for other projects and could be adapted for this one.

For the purposes of putting a system together, it appeared as though the required industrial (dust proof, water proof and shock mounted casings) are available locally. Other standard units used for systems engineering projects are also readily available. These include the required powering facilities and adapters, interfacing cards or units for distributed computing, facilities for the various data communication requirements, computer paraphernalia etc.

2.4.4 Local Procedures

A factor investigated for its potential effect on the obtaining of the agronomic data, was the *farming* practices relevant to the SVFAP. These included the harvesting techniques (direct cutting or wind-rowing), vehicle traffic patterns and crop management practices.

2.4.5 Existing Equipment

The Harvester

Old harvesting techniques entailed the counting of bushels as a means of measuring yield. Harvesting using the combine facilitated the storage of the grain in a catch chamber. Using this technique, the grain has conventionally simply been weighed on a field to field basis to obtain a measure of relative field crop yields. No means of obtaining instantaneous yield readings has been used in conventional farming techniques.

The combine harvester used in this project was the new John Deere 9600. To be able to implement the project effectively, the combining processes and equipment utilized on the combine needed to be understood. For our purposes it was necessary to have a fairly comprehensive understanding of the elements which may effect combine operation and the results of the yield measurements. The technical manuals and associated pamphlets and circuit diagrams of the John Deere 9600 combine harvester were consulted (for the details of the equipment, see [17]).

The combine was also inspected for its powering and space limitations. This was required in order that the system could be adequately powered and accommodated on the vehicle.

The Applicator

To understand the aspects of the control required on the applicator, the technical documentation ([31]) and the technical staff associated with the Slimjan controller on the Kynoch applicators were consulted.

The Slimjan controller on the applicator is a fairly intelligent controller separate to the on-board processor. It facilitates the activation of a hydraulic pump based on the signals obtained from a flow meter in the line to the booms and a proximity sensor on the drive axle to pick-up ground speed. The hydraulic pump drives a hydraulic motor which proportionally drives a centrifugal pump, pumping applicator from a product tank to the booms.

For the purposes of design, the electrical characteristics of all the signals were determined. The use of a flow meter instead of a pressure meter (as was the original configuration), has the advantage in that the instantaneous amount of liquid fertilizer applied has a linear relationship to the instantaneous flow and an improved turn down ratio over the range of interest.

The applicator was also investigated for its space limitations and its powering facilities. In this case, there existed a 24V isolated inverter supply used by Slimjan. This optional power supply is cleaner than the 12V battery supply.

Basic control theory and a study of a few of the more advanced techniques is required for the implementation of the application phase. Criteria for consideration in this application are transient responses, variable setpoints of fertilizer distribution rates, controlled mixing of chemicals and the controlled navigation of the relevant vehicle.

The Sampler

The sampler is simply a Volkswagen shell with a borer mounted on the side. The borer is operated by means of a crank handle and extracts a core of soil at the desired location. There is the conventional 12V battery supply and ample but unprotected space for the SVFAP equipment.

Chapter 3

Deductions from Site Specific Farming Investigation

The information from the literature review and project investigation could be collated and further conclusions drawn. These deductions are discussed under the same headings as those used for the previous chapter on the project investigation.

3.1 Agronomic Considerations

Based on the study into fundamental agronomic practice, the following was inferred concerning how to deal with spatially variable phenomena.

3.1.1 The Management of Field Soil Variations

As intensive soil sampling is tedious and costly, it is preferable to first determine the yield maps to glean as much information as possible. A basic strategy for the treatment of the field would be as follows:

1. A blanket application of fertilizer may still be required for fields with small yield variations. That is unless obvious heterogeneous characteristics are apparent.
2. Fields with large yield variations should be treated carefully. Yield variations can be caused by many separate mechanisms. Some of these mechanisms will aid the production of the crop whilst others will hinder it. It

would appear as if the type of soil largely determines the fertility and therefore the ability of the crop to absorb the chemicals, whilst extreme moisture sinks may result in the chemicals being drained away from the crop unnecessarily. If the variations are largely determined by controllable factors (chemical and yield results correlate for example), then spatially variable application will have the greatest benefit. If this is not the case then not much can be done chemically to substantially rectify the yield losses due to these factors. (This is not to say that these factors should not be taken into consideration in the variable treatment of the field.) It is therefore necessary to determine whether the chemical variations are well correlated with the yield variations. For these correlations to take place, a certain amount of soil sampling will be inevitable.

3. In the treatment of the field, areas with low chemical concentrations should be supplemented up to an *optimum* level depending on the type of soil, soil hydrology etc. These may be high yield soils worthy of special treatment and increased application levels. Areas with higher concentrations should be supplemented only to a level which is in accordance with *their* yield bearing capacity. Again that would require a consideration of the soil type, pH, hydrology and yield predictions in that soil (i.e. its fertility). The average of the variable application levels should match relatively well with the uniform application rate determined through conventional means (i.e. by means of a couple of sparse soil samples).

3.1.2 A Soil Sampling Strategy

It is clear that the harvesting information will be fairly detailed. For fertilizer recommendations to be made, the results of field soil samples are required. As this is the element that, in the implementation of the SV Fertilizer application project, will be the most time consuming and costly procedure; the determination of an effective sampling strategy is imperative. This topic is a little more agronomically intensive and the interpretations could be subject to misconceptions.

There seem to be many differing opinions as to how intensively one should sample but the overall impression from all the available literature is as follows:

- A heterogeneous field is adequately described in [22] as when a field's spatial variability is controlled by topography, vegetative growth or surface wetness across the landscape extent. If the field appears heterogeneous in such physical attributes, and these effects appear to be dominating the yield results, then it is proposed that the field is divided up into areas dictated by common features. This can be done using GPS, logging sections of the field

in which a soil sample will be taken as representative of that section. This will constitute the soil map for that field. Alternatively, if this approach is too tedious, perhaps sampling on a 2 and a half acre grid (as Bill Holmes in [18] has been doing) would be a suitable and less arduous alternative. The sampling information obtained in this way can still be correlated with the yield information and the field divided into sections after the sampling has been done. Decisions such as those described above requires experienced and knowledgeable judgments to be made by agronomic experts.

- In the event that the field appears to be homogeneous (or even mildly heterogeneous) in nature and is confirmed by the yield results, the cost of sampling even in such a sparse way as described above may not be justified. In such a case, conventional fertilizer recommendation techniques and uniform fertilizer distribution should be employed. These conditions could be determined by an expert's 'knowing look' and the analysis of the yield results.
- The crunch comes when a field appears homogeneous or mildly heterogeneous but shows high yield variances. In this case it is recommended that intensive sampling is carried out on a small section of the field. These analyzed samples should be processed (as will be described in Section 6.5) in order to determine whether the chemicals of interest are spatially dependent upon one another or not¹. Should such a spatial dependency exist, 'intensive sampling' would mean that samples are taken on the maximum grid through which more detail can be extracted by means of an interpolation technique making use of the spatial dependency. These grid sizes are still to be determined through procedures yet to be described in the upcoming sections, but would be on about a 30m grid if K or P were the quantities of interest. Continuing with the same degree of 'intensive sampling' throughout the field will produce highly accurate soil sampled data with a minimum amount of sampling.
- Should the result of the processing show inadequate spatial dependence of the quantities of interest, then classical statistical techniques will be employed for the analysis of the results. The intensity of sampling for the entire field will then have to be decided in accordance with the degree of yield variation that occurs in the field. In this case one may wish to sample more intensively than what is described as 'intensive sampling' for spatially dependent samples. Alternatively, if there is much less spatial variation in yield, a large sampling grid (a two and a half acre grid for example) may suffice. There have been applications in which grids of 2 to 4 acres were

¹This procedure may not be necessary if tests for spatial dependency are done on all the chemicals of interest and consistently show that spatial dependency exists.

used. One quote relating to the determination of the size of this grid was: “These areas (grid sizes in which soil samples are taken) would have to be small enough so that each area would have conditions similar enough to be considered essentially the same.”

For intensive sampling to be done, efficient and accurate soil sampling techniques are required and the existing ones may need to be revised (see Section 2.3.3).

3.2 The Positioning Technique

3.2.1 Positioning Technique Requirements

The requirements of the positioning system are as follows :

1. **FORMAT:** Provide positioning information in a format that can easily be read and manipulated. Provide facilities for the conversion of the measurement's datum and co-ordinate system to one that is relevant to the current application.
2. **SPEED:** Because of the dynamics of the yield analysis and application phases of the project, the positioning system is required to produce positioning information on a real time basis. This is especially critical in the event of the applicator phase where the delay in receiving the positioning information is critical to the control constraints implicit in this application.
3. **POSITIONING ACCURACIES:** There are two applications of a positioning system. One is for the identification of a grid cell (or monitoring) and the other is for navigation or guidance. The former requires less stringent positioning accuracies and both are dependent on the grid size in question. The grid size can be the management cell determined by the smallest grid size in which different amounts of fertilizer can be applied. Alternatively, the grid size could be the size of the physical cell which is determined by the size of the relevant vehicle's implement width. The positioning requirements are determined by the accuracies desired in cell identification and is therefore ultimately dependent on the size of the 'management cell'. If navigational automation is required, then further accuracy constraints are required. These are determined by the accuracies considered suitable for the application in which the automation is required (see Section 2.2.1). This latter accuracy requirement is a direct function of the 'physical cell' size. That is, for a specified positioning accuracy, the decision to implement it in

a guidance application is determined by whether the guidance will improve the driving accuracy or not and be suitable for automated navigation in the application for which it is required. It is very likely that for a small physical cell size the accuracies associated with the positioning system will not improve the drivers skill.

4. **OVER-ALL ACCURACY:** The accuracy with which the yield is determined or fertilizer applied is a product of the accuracies associated with the actual measurement or application (averaging errors) with the positioning accuracy in the grid cell and the drivers accuracy in having a full boom-width of crop or in preventing skips or overlays. As an example, if it is desirable to determine the yield within 10% in a particular grid cell, a meter with a 3% error will be downgraded by a positioning error of 5% and leave a small leeway for driving errors. If any of the errors are substantially larger than the others then it will reduce the stringent requirements of the other elements in their performance.
5. **QUALITY ASSURANCE:** This aspect would become a vital consideration the more a SVFAP relies upon the accuracy and integrity of the positioning technique (if automatic steering was implemented for example). A certain amount of QC (see Appendix B) should be implemented in the applicator phase to ensure that the right amounts are being distributed in the right places. Similarly for the other two phases in that there needs to be some warning as to the integrity of the data obtained.

3.2.2 Navigation

There were two instances in which the need for navigation was encountered. The first was in the implementation of the sampling phase of the project in order to set up a more accurate sampling grid. The second was for the proposed implementation of leaf samples at the same positions at which the soil samples were taken. The latter is not an official phase of the original project requirements. If it were required that leaf sampling be carried out, then the hardware would have to be adapted so that the mobile station can be powered and made mobile about a field with a half grown crop. Nevertheless, navigation becomes a necessity if soil sampling is to be carried out at accurate positions.

Many GPS receivers provide navigational features sometimes as part of the receiver or sometimes as a separate unit which can communicate with the receiver. For our purposes however, it would be required to develop our own navigational display to keep the unit contained to one user interface providing all user requirements. This is a relatively simple matter using the positioning strings from the

GPS receiver.

3.2.3 Practical dGPS Implementation

With the current state of the satellite constellation, 'mission' planning to ensure that a suitable satellite configuration which will enable position accuracies better than say 10m (a GDOP of less than 3 in this case), is unnecessary. This is because the incidence of both GPS receivers seeing less than 4 satellites and having a GDOP higher than three is unlikely in this region at present.

To detect whether both receivers see the *same* 4 satellites for correct differential corrections to be made, it would be necessary to have access to a string of the correction data at the mobile station. This is necessary for a real time applications such as that of the fertilizer application phase. Post processing of the logged correction data would suffice for the implementation of the other non real time phases and would still illustrate dGPS operation. This additional consideration for the detection of the correction data would become a necessity the larger the distance between the reference and mobile receivers.

It would also be required that the GPS receivers be remotely controlled so that the software could chose the type of information to be accessed from the GPS receiver; whether it be position calculated cycle reports or cycle reports of the differential corrections.

3.3 Considerations for Soil Spatial Variability Compensation

This section serves to introduce the proposed SVFAP design criteria. Within this discussion, the tasks and hardware requirements for the development of the SVFAP solution are given.

These specifications of the SVFAP is based on the findings of the literature review and *adds* further insight to those things already discovered. Other site specific farming solutions have been analyzed and the basic features of these systems extracted for our specifications. In addition to this, the refinement of the specifications was done taking the existing equipment and available technology into account.

The specifications of the various phases of the SVFAP was done *simultaneously* to achieve the correct project development of the 'black box' criterion. This

discussion of the various SVFAP phases makes up the first part of this discussion.

A description of the hardware solution to each phase of the project forms the second part of this discussion and is described in terms of the black box design and black box peripherals.

3.3.1 SVFAP Phases

1. *The Soil Sampling phase:* The on-board positioning system would provide the positioning information to the computer. The computer will then be required to operate in a mode to produce a label for labelling samples. Sampling would probably be carried out by some borer obtaining samples as the 'car' moves over the field. This amounts to manual testing. Another, more expensive option and possible project improvement, would be to investigate the inclusion of an analyzer. The processor would then act on the inputs from the positioning system and the analyzer to immediately generate the chemical maps required for the formulation of the application maps.
2. *The Spraying phase:* The development of the control specifications for the distribution of fertilizers in accordance with the predetermined application map is required. The hardware would have to be extremely robust to handle the hot, dirty and wet agricultural conditions. The computer system would be required to operate in a mode to simultaneously serve as a data base for the predetermined data and provide the intelligence for the system (interlocks and relevant application rate determinations). The requirements of such a computer system would be that it handles large quantities of data to provide the corresponding spray 'rate' maps quickly. The required interfacing between the positioning system, the computer and the tractor control system needs to be established. The existing 'slimjan' controller may require upgrading to deal with the rate at which the control setpoints are changing. The development of a controlled system to mix the fertilizers may also be required depending on mixing necessities. The system as a whole should be compatible or an easy extension of the existing method of distributing fertilizers. For example, if only one chemical is to be distributed, then it is only necessary to fill up the holding tank when it is empty. If, however, the mixing is done on the tractor itself (to save mixing at the factory) or if more than one chemical is to be distributed at a time, then transporting, loading and volumetric inefficiencies become vital considerations. The inclusion of nurse tanks are a possibility. Liquid fertilizers are also advantageous as they can be loaded from ground level.

The applicator would therefore be required to have the following characteristics:

- reliability and ease of repair.
 - precise application at the desired rates. i.e. the spraying mechanism should ensure a uniform flow and mixture across the boom width by checking the deliveries at each nozzle.
 - transient response times to handle a certain set maximum tractor speed. Using the on-board computer, the system could be made 'smart' enough to change the setpoints ahead of time. Factors which will effect the transient times are the length of hoses from the mixing point to the nozzles, the diameter of hoses whilst still maintaining uniform nozzle pressure and the rate at which pump speeds can be changed.
 - the ability to maintain a uniform spraying pattern despite the varying rates and land topography. This could probably be accomplished by using special or multiple nozzles and by doing some kind of matrix operation on the setpoint maps which are generated based on prior knowledge of the field topography.
3. *The Yield Mapping phase:* The combine harvester needs to be instrumented to provide an output of yield at each position. This involves developing a means of measuring the yield; either continuously or in a type of batch mode through some weighing or alternative technique. The positioning system needs to be configured for this application and the inclusion of it in a system to guide the operator needs to be considered. A computer system with the necessary interfacing and computing mode to act on both the inputs of the positioning system and the harvesting information to generate reports will also be designed.

3.3.2 The Black Box Design

As the name indicates, this element of the project has to be portable to all three phases of the project. It must be able to interface to all the peripheral equipment required by each phase and operate in various modes according to the relevant phase. The 'black box' would also have to be extremely robust to handle the hot, dirty and wet agricultural conditions.

Some of the requirements of the 'black box' would include:

1. The cost of implementing spatially variable applications must be less than the money it will save or generate over a reasonable amount of time. This does not make our proposed implementation of using GPS a very feasible

option for the farming community. It is more feasible however, for an input supplier to provide the service implementing the superior technology, as the SVFAP will be implemented by more than one user there will be more scope for returns.

2. As mentioned, a user friendly and relatively simple operation of the SVFAP is required in the agricultural application.
3. The description of the hardware requirements and the operation strategy needs to be defined.

Based on the studies of agronomic principles, certain soil sampling strategies were established. There are operational strategies that need to be defined for the implementation of a SVFAP in general. It would definitely appear as though the interest is in gleaning as much information from yield maps as possible and using this phase as the first step in the treatment of the field. Intensive soil sampling should be the last consideration due to its impracticality, and should only be implemented in conditions as were described in the soil sampling strategy.

Black Box Hardware

A dedicated computer with the necessary interfacing (i.e. distributed control system (DCS) and networked communications, DAU or input/output card depending on the number of inputs in the final implementation) is required. The black box will have to have different computing modes for the various phases. These modes could be programmed in 'C' to handle the relevant interlocking functions, database manipulations and processing requirements.

A simple I/O card directly connected to the bus of the on-board computer within the black box should suffice. This solution should not be expensive should it need to be replaced by a more elaborate interfacing configuration if it were required by further refinements to the system.

As the final implementation will most likely require a dedicated computer without the need for an elaborate user interface, a notebook may then be useful as a portable interface between each system to communicate with the dedicated computer by means of a serial link. This will be useful in the event of any programming alterations that need to be made. The latter description of the final implementation infers that a simple operator interface will be used instead of the laptop for the initiation and control of the program in its relevant mode. A four line by twenty character LCD screen with ten or so push buttons for program initiation etc. should be adequate.

It had been decided that a system employing dGPS positioning would be optimal. In line with this decision, a conference on dGPS was attended which provided valuable information as to the current developments within the field of GPS and the relevance of the trends within the field to our application. It seems as if the great distinction between accurate surveying applications and navigational GPS applications is becoming less definite. This is due to the potential application of adapted but more accurate surveying techniques (cm accuracies) for real time mobile navigational or similar positioning applications such as ours is. If this technology was to become economically feasible and without its few current limitations (as is predicted), then its application in this field of research would greatly enhance system accuracies and facilitate the implementation of automatic steering.

DGPS needs to be assessed in the agricultural environment and suitable strategies developed for the optimal location of the reference stations.

The development of the positioning system for operator guidance will be considered in the commercial implementation. This will be done through the operator interface used in the final system.

A HF DTL has the capability to diffract more readily around the obstacles in the agricultural environment but has a shorter range than that of UHF. If HF or VHF was to be implemented for this application, repeaters may become a requirement. Single Sideband (SSB) HF or VHF with repeaters are the recommended options for the DTL but may prove to be troublesome when acquiring a frequency allocation.

A data rate faster than 40bps is required for the transmission of the RTCM SC-104 type 1 message of dGPS position corrections for an update rate of less than 12s (according to [40]). A 12s correction update rate is an adequate requirement considering most representative levels of Selective Availability (SA) and the associated correction fluctuations (second order characteristics) to be accounted for in the correction data extrapolations.

The baud rate between the GPS receivers and the modem and that of the DTL should be approximately 5:3 or higher. This will ensure that corrections do not 'pile up' in the modem buffer due to slow processing rates, preventing old corrections being used by the system software.

The standard RTCM position correction data string has an error detection capability and therefore does not require packet (such as AX25 protocol) transmission. Simple stream data transmission is suitable for this application.

A configuration for the implementation of the positioning and computing requirements was decided upon. The details of this configuration is represented in block

diagram form in Figures 3.1 and 3.2.

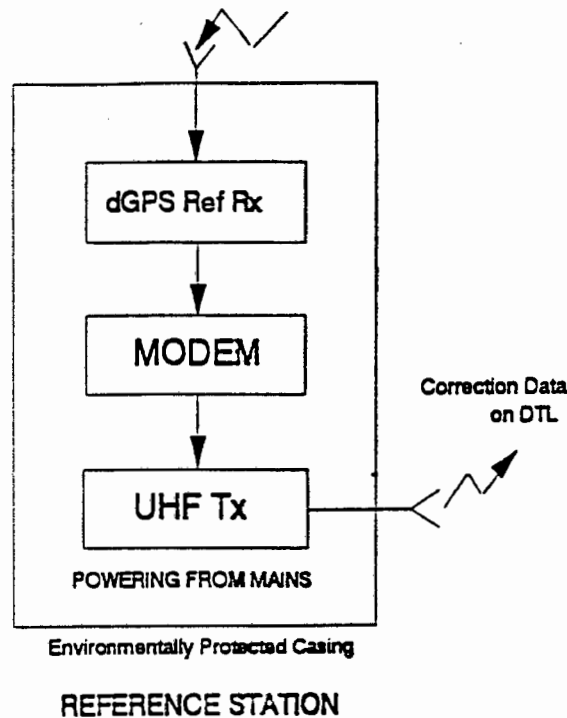


Figure 3.1: Reference Station

A system employing dGPS will then consist of the required receivers, a Data Transmission Link (DTL), a suitable housing and powering facility, suitable interfacing for the positioning information and other sensor signals as well as a means of processing the information and controlling the respective phase of the SVFAP.

Black box software

The software requirements of the system are critical as they are required to process the location information and other sensor inputs as well as provide the set-points required for the control of other black box peripherals. It must also provide the interlocks required for the general operation of the system. In addition, it is also required to process the information into a format that will make it practical for analysis purposes and portable to analysis software (E.g. GIS).

A navigational guide and operator interface:

Previous software that has been developed has operated in such a fashion so as to continually update the operator interface to indicate the functioning and status of the system. Navigational messages have also been displayed on the operator interface for guidance. Full automatic steering has also been proposed. The

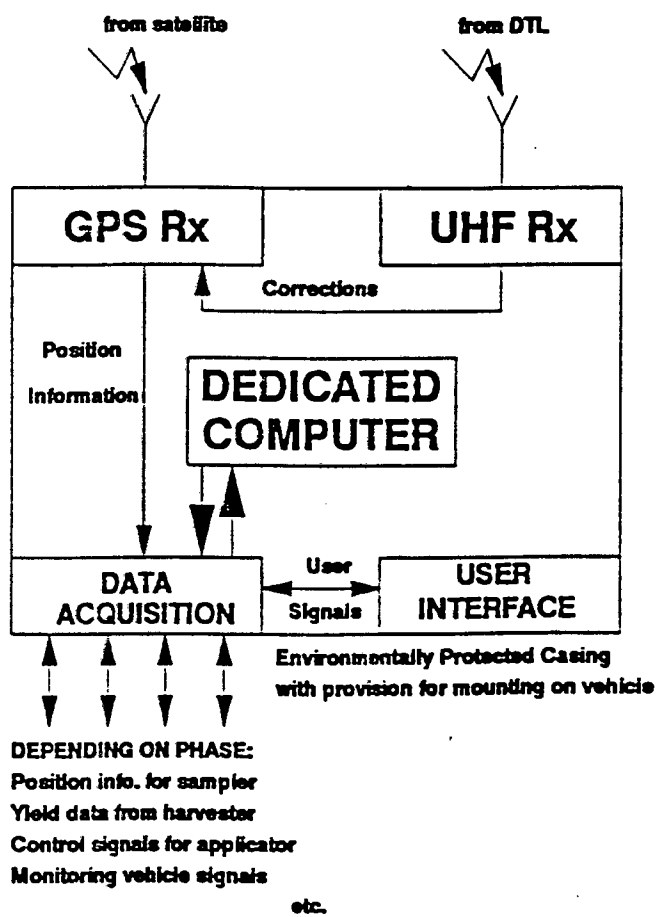


Figure 3.2: Black Box OR Mobile Station

guidance was realized through the use of the previous two position fixes and a projected position fix to indicate in a simple graphical representation, the driving accuracies of the operator. Some of the details of this software has been described in the following Section 3.2 on 'developments in the implementation of the positioning system'. The need for the simplicity of the graphical representation was stressed when considering the predicament of the operator in having to reference a screen whilst attempting to drive and his temptation to ignore it altogether. If, however, the operator gains confidence in this facility, then it would certainly improve the driving accuracy and prevent the operator from looking back on his path for vehicle alignment. Another major advantage of such a guidance system with suitable integrity, would be in its ability to be implemented at night time. Farming in the dark may become a requirement if there are time limitations on the farming operations or if preferential weather conditions, such as less scattering winds, prevail at such times.

Commercial software:

If the black box software were to be developed locally, C or C++ (OOP) languages are preferable. In addition, some of the considerations and recommended data structures discovered in the literature review could be implemented.

As for the commercial software that has been developed (Agricad mapping and analysis software for example), there is something to be said for not re-inventing the wheel, but there are a few other points to note:

- As this software includes most of the GIS functions, it is likely to be fairly costly. It may also require the inputs of standardized types of data and therefore be limiting on the GPS, sprayer and computer configuration. This will pre-define a large part of the project and will result in the acquisition of equipment and a system which is not locally maintainable. This latter constraint was one of the primary requirements of the original system discussed in the project requirements review.
- Unless the software can be adjusted to allow the input from agricultural sensors (i.e. the application extended to the other two phases of the project) and allow facilities to do the required averaging and adjustments, then it will result in the software for the 'black box' becoming fragmented and eliminate the portability requirement of the project.
- The software described here is unnecessarily complex for its inclusion on the vehicle itself as it will be far more demanding on the microprocessors performance whilst being too complex for operation by a vehicle operator. Much of the features offered by it are unnecessary for its basic implementation. It will not be necessary for an operator to do spreadsheeting analysis

or to view the field's history during the application phase for example.

The details of how some of the software was developed would be of interest however, but a simpler and less sophisticated operator interface is recommended for this implementation.

The interfacing of sensor signals:

The handling of the *raw data* must also be accommodated in the software. This may involve the measuring of the relevant parameter, the time flagging of the information, the relevant filtering and adjustments according to predetermined models and final interpolations and re-sampling. Corrections for ground speeds and width of cut or application also needs to be accounted for on each individual measurement.

Processing yield, soil and positioning information:

The yield detection is described in [4] as the starting point in establishing a closed loop control on the SV application of fertilizing inputs. Their reasoning is that the withdrawals of nutrients and their replacement by straw or roots gives the initial indication of the potential of the next harvest as well as a means of comparing results.

One typical yield measuring application took measurements in .33 and 1 sec time intervals travelling at an average speed of 4 or 5 km/h. Software programming was required to filter the yield information as well as time match it to the position information.

This implementation constituted a mapping package which could do the required interpolation and generation of yield sample vs position databases. There are such commercially available mapping packages. These packages include some of the features of conventional GIS packages in that they can produce graphical yield maps and its associated databases. The fear of implementing such software is again that it is not local and that it facilitates a software configuration that redetermines a hardware configuration. The latter consideration also introduces another potential difficulty as the output of the processing may not produce information in a standard form acceptable to the GIS package being used for analysis.

Post processing can be done on the positioning information in the yield and soil analysis phases of the project as the real time positioning requirements are not as stringent a requirement in these cases. There are such commercially available packages from GPS receiver manufacturers for this purpose and can greatly improve the positioning information accuracies. Such post processing software

has found its application in other continually mobile receivers such as in aircraft applications. It can be used for differential GPS applications.

Another point worth mentioning is the usefulness of ASCII text, as it is the easiest format to be entered or edited in an agronomic analysis configuration. It should therefore be ensured that the output of the phases of our system is in the form of such a fixed length or delimited ASCII file compatible with most GIS software packages.

In the generation of the application rate maps an n levelled threshold heuristic can be applied to the spatially variable data in order to determine the areas requiring certain application rates. The ' n ' corresponds to the number of application rates that the system is designed to be capable of handling.

3.3.3 Black Box Peripherals

In a refined implementation of this project, it becomes apparent that there will be many variables requiring sensing. Some of the obvious parameters will be yield measurements and ground speed indications. In addition to this, many modules will require control signals. Some of the yield meters and other peripherals were described in Section 2.3.2. Based on this study some of the observations regarding the peripheral operations are described here.

To facilitate all this information handling, sophisticated interfacing to the controlling computer is required. That interfacing has been dealt with previously. This section deals more with the means in which various parameters are sensed.

Some of the requirements of the 'black box' peripherals would be:

1. The accuracy of the speed sensor should be such as not to degrade the yield flow measurement accuracies or effect the fertilizer controller's rates beyond the designed accuracies.
2. All peripheral sensing on each vehicle that will have an effect on the current phase of operation needs to be decided upon. This decision will be based on a sound knowledge of the existing equipment and processes upon which the project phase is based.
3. The accuracy of the yield meter need not be as stringent if the accuracies associated with the positioning or driver's skills are much larger (See Section 3.2).

The Sample Labels

In the simplest design configuration of the sampling phase, all that is required, in addition to the black box configuration is a means of recording the sample positions. In this case, the peripherals that need to be interfaced to the black box, would be a cab printer of some kind and the operator interface.

The Yield Meter

Both the commercially available yield meters and those which were developed for experimental purposes, can be divided into two groups; volumetric and mass flow meters. The volumetric meters require density information in order to determine the grain tonnage harvested. These meters comprise of those measuring grain levels as well as those measuring grain flow rates (radiometric and force plate types for example).

The *Ceres* RDS meter implements volumetric measurements by means of the percentage of light displaced by the levels of grain on the elevator auger of the combine. This meter is accessible through local agents. The meter appears to be comprehensive and quite reliable despite the concern for the tilting errors. In addition to this, the feasibility of using optical remote sensing for yield determination was considered and information enquired after. This option does not yet appear to be feasible, but this conclusion should be re-assessed when more satellites become available and more practical data has been obtained.

Filtering and averaging considerations on the yield information needs to be considered carefully so as not to lose any valid data. Dynamic modelling and interpolation procedures are basic requirements for the yield map generation.

An Operator Interface

In the commercial SVFAP solution, a simple operator interface needs to be developed. This unit needs to be interfaced to the dedicated computer and should receive the highest priority on the communications network.

Real Time Sensors

Apart from a sensor which is required to interpret the yield of a field continuously, there are other sensors which exist which can determine other field parameters on-the-go. These sensors can determine various soil characteristics otherwise only

available from soil sampling. Such sensors threaten the 'temporally separate' implementation of this project for if it were possible to process the sensor's readings fast enough, a knowledge based system could be consulted and the application rates altered automatically as the vehicle moves over the field.

An 'automatic' implementation is still not feasible and will not be until 'real time' sensors are developed to interpret pH, phosphorous, nitrogen, potassium, organic matter, soil moisture and micro-nutrient levels.

A great deal of work is being done in nitrogen sensing as automatic application of nitrogen would be most beneficial considering the mobility of this nutrient. Illinois University provided some literature on their work but automatic nitrogen application is not yet a reality commercially. A soil moisture level detector can benefit other elements of spatially variable agriculture. Planting depth and variable irrigation schemes can be made to be a function soil moisture levels.

The use of organic matter sensors, may have an application in providing yield comparisons at harvest.

These developments could improve management precision in the event that they could be used in conjunction with the temporally separate implementation.

Application Control Equipment

The implementation of the technology on the vehicles required for each phase of the SVFAP, also needs to be taken into account.

For improved environmental benefit, it would be preferable if the chemical requirements of the soil could be distributed in a single pass of the field. This would result in less soil compaction facilitating more soil aeration, drainage and nutrient uptake whilst reducing fuel usage. This could be achieved through applying a single fertilizer compound that would fulfill the average requirements of the field through variable rate application. In this case, the compound mixture could be produced at the factory and it will only be necessary to fill up the holding tank when it is empty. If, however, there is more than one major chemical with large spatial concentration deviations then mixing would be required to be done on the tractor itself. (One American company has produced an applicator which is capable of blending and spreading six dry inputs at a time.) The same would apply if for example, the trace elements were required to be supplemented in addition to the basic chemicals. For these purposes equipment that can mix and apply multiple compounds on the go would be required. The control problem becomes far more complex in this situation as the rates of each compound would need to be controlled individually and transporting, loading and volumetric inefficiencies

will become vital considerations. The inclusion of nurse tanks are a possibility. Liquid fertilizers are also advantageous as they can be loaded from ground level. Liquid application could probably be achieved through a hydraulically driven positive displacement pump and slip control.

Chapter 4

Description of Field Test Feasibility Studies

The major emphasis of the rest of this thesis will be to describe, in detail, the first set of field tests which took place in April. These tests were aimed at assessing the suitability of dGPS in the agricultural environment and that of the system design in implementing the sampling phase of the project. The results of these tests will be given in the next chapter. This chapter will describe the motivation for the tests, give a brief description of the tests that were carried out and the hardware configuration used in the tests. Details of the field test preparations and the description of the actual methods used in the field tests will be given in Appendix C. The illustrations of the tests will be provided in this chapter so as to facilitate a better understanding of the test inferences to follow.

DGPS needed to be tested for its suitability in providing location data of suitable integrity. The effectiveness of each phase of the project in the agricultural environment and under the same conditions in which it will finally operate also needs to be established. For this reason, dGPS required site testing as do all phases of the project and real readings and simulated operations need to be undertaken.

Due to this project development being limited by the farming cycle and equipment availability, it was decided to develop each step of the SVFAP in isolation at the most opportune time. This required the separate development of a suitable engineering solution for the soil sampling, harvesting and application activities of the project. It was however, decided that it is necessary to keep all elements of the SVFAP in mind throughout the project development in accordance with the black box principle.

One field is sufficient to prove the feasibility of the engineered solutions of the

SVFAP. If the agronomic effectiveness of the system was to be tested, comparative yield results would be required. In this instance, data from a few seasons and many fields would have to be collected in order to generate a statistically sound basis from which to work. Using one field however, simplified our reference station powering constraints in that, for these tests and on these fields, it was feasible to power the system from the homestead. Conventionally the powering requirements of the GPS reference station would be that it be remotely powered.

4.1 Motivation for the Field Tests

The testing of dGPS equipment and the implementation of the sampling phase of the project, is necessitated by the following observations:

1. It is well established that the published specifications for this GPS technology is *unreliable*. This is due to the fact that levels of Selective Availability are still subject to changes. The effects of this and over-zealous marketing is not adequately reflected in the specifications quoted by the manufacturers. It is therefore necessary to establish the validity of these specifications in a *typical field* through comprehensive testing for the make of GPS receiver under consideration.
2. Despite the assurance offered in theory regarding GPS, the establishment of the suitability of this technology in our *practical* implementation needs to be undertaken (as motivated in above discussion). This is especially true considering that the RL DL dGPS TRIMBLE receiver set would *cost* approx. R130.000,00 and the RL2 SVee6 dGPS receiver combination, R70.000,00.
3. Any unforeseen practical limitations due to our *specific application* (E.g. sampling in a typical field) of the technology needs to be established.

4.2 What Tests?

Just as it was necessary to establish a suitable sampling strategy, it is also required to quantify all other SVFAP strategies. These include the specifications of the testing of the positioning technique and the procedures that will be required for the effective testing of all the phases of the project.

After all the software for the logging and the processing of the field data had been tested in the laboratory, the following field operations were to be implemented:

1. The dGPS equipment was to set up in the field and the effectiveness of the data link established.
2. To test that differentially corrected positioning information (no loss of LOS) was available throughout the farm area. This would require the establishment of the reference station on a high site in the region. This test was aimed at validating the suitability of the DTL (i.e. the UHF link and antennae combination) and the terrain limitations of the environment.
3. To log positioning data at various areas within the farm area that could demonstrate some of the terrain dependency effects that need to be investigated. (i.e. areas that could simulate loss of satellite lock, loss of DTL and multipath effects)
4. Carry out some of the standard receiver tests for completeness (and for the possible comparison with other receiver sets). The other possible receiver tests will be carried out whilst completing the remainder of the field tests. It should be noted that as much as the aim of these tests is to test the technology, we are in effect primarily testing the performance of a particular make of receiver.
5. Static tests are required for establishing the accuracies expected of dynamic applications. The expected accuracies for each set of terrain independent limitations on accuracy (E.g. No. of satellites and levels of SA) and the determination of measurable parameters indicative of these occurrences was to be assessed. These tests typically entailed the determination of the standard deviations representing positioning accuracies for a position of known co-ordinates.
6. Once real time positioning is required on a mobile station, then it needs to be checked that the correction update rates and extrapolations, filter algorithms and position extrapolations are working adequately for the dynamics of the situation in question. The same standard deviations should be obtained for the dynamic solutions as for the static ones. The test will therefore basically be comprised of setting up a grid of surveyed way-points and moving about them at typical speeds to log their positions. These tests were to be carried out in a typical field to establish the terrain dependent limitations and on an open road within clear LOS of the reference station to establish the terrain independent limitations.
7. As part of the field tests, it was hoped that the equipment could be used in assessing its suitability for one of the phases of the SV Fertilizer Distribution Project. It was therefore hoped that the sampling phase could be carried out for a section of the field using the positioning information. This exercise will

also give insight into the limitations and considerations for implementing this on a larger scale.

4.3 Hardware Configuration

This section describes the hardware configuration of the equipment used in the tests and will serve as a reference to the following section in which the tests are described.

Based on previous discussion, no mission planning or logging of the correction data string took place. The latter consideration was vetoed because of the relatively small distances between the GPS receivers (Max. 10km) making it unnecessary to check that the same set of satellites are in view to both receivers.

A UHF telemetry link with no repeaters and omni-directional antennas were used for the DTL. There was no necessity for any frequency licenses as the equipment contractors (Underwater Surveys) had obtained one for this UHF link. The transmission power was around 9W but a high power option of 30W could be selected and combined with a yagi directional antenna if required. No requirement for the latter configuration was found. The correction data was transmitted at 1200 baud, transmitting 6 to 11 words of data every half second. This is within the 40bps limit required for correction updates (see Section 3.3.2).

With a system baud rate of 9600 baud, the 5:3 ratio criterion is superceded by this ratio of 8:1 ensuring the most recent corrections being used at the mobile station (again see Section 3.3.2).

A 12 channel L1 Trimble reference GPS and a 8 channel L1 Trimble differential receiver was used in these tests.

Figure 4.1 indicates the hardware setup and port connections of the reference station at the trig beacon. This configuration indicates only one of the powering options implemented during the tests (described in the following section). The transmitter was run on the low power (9W) option and proved to be adequate for our application. The power supply feeding it however, required to be able to source currents of up to 20 Amps on every half second transmission of correction data. The UHF Tx supplied power to and received RS232 handshaking with the GPS receiver by means of a separate connection to the GPS receiver's auxiliary port and 1 pps port. The diagram also shows the connection to the self powered PC (notebook) by means of a directly connected (DCE to DTE) null modem serial connection. This connection was only made initially for the logging of the setup report of the pre-programmed GPS receiver. The powering of the GPS receiver

by means of the power adapter and the 3.5A current limited power supply was an optional extra to alleviate the demands on the other power supply.

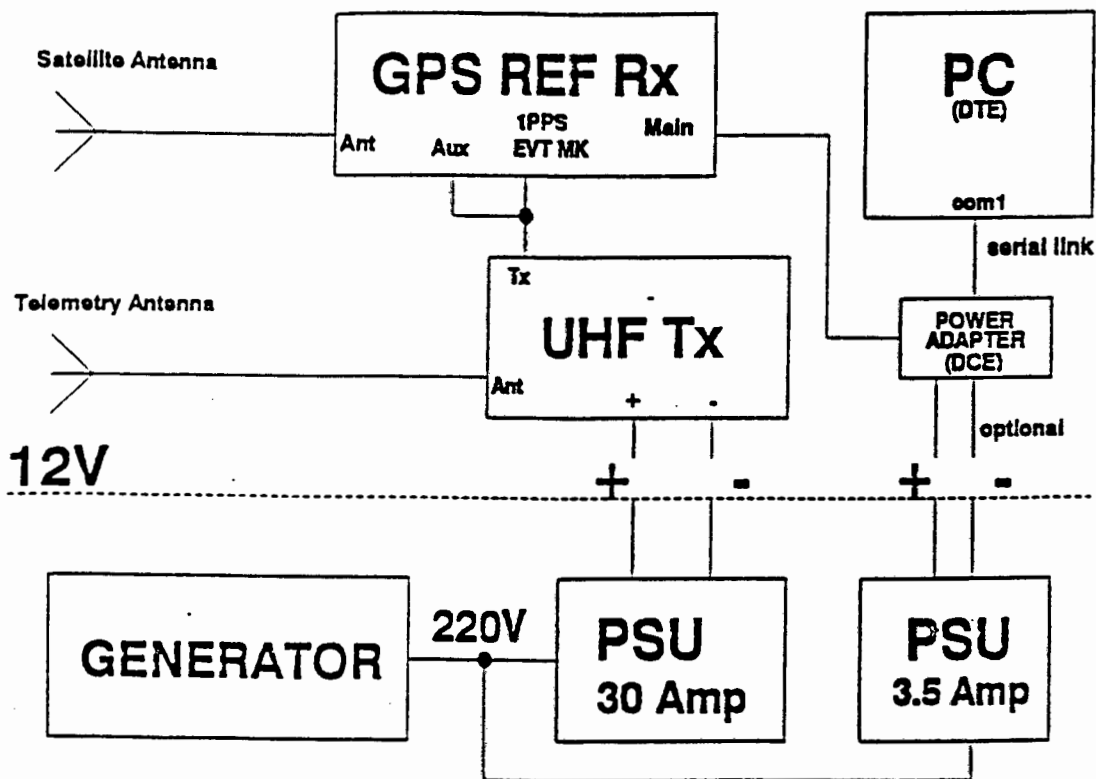


Figure 4.1: The hardware configuration of the reference station at the remote trig beacon

Figure 4.2 indicates the configuration of the mobile station on the Land Rover. The 12V battery (located under the passenger seat) drove the UHF receiver directly and supplied the GPS receiver via its power adapter unit independently of the UHF receiver. The notebook was powered via the cigarette lighter and logged data from the GPS receiver according to the test being carried out.

Figure 4.3 indicates the configuration of the equipment for the static tests in which all the equipment was housed together and powered from mains. The GPS Reference receiver was again powered via the UHF transmitter and the GPS Differential receiver directly through its power adapter. The notebook was again set up to log data from the GPS Differential receiver as dictated to it by the current test and was independently powered from a mains adapter.

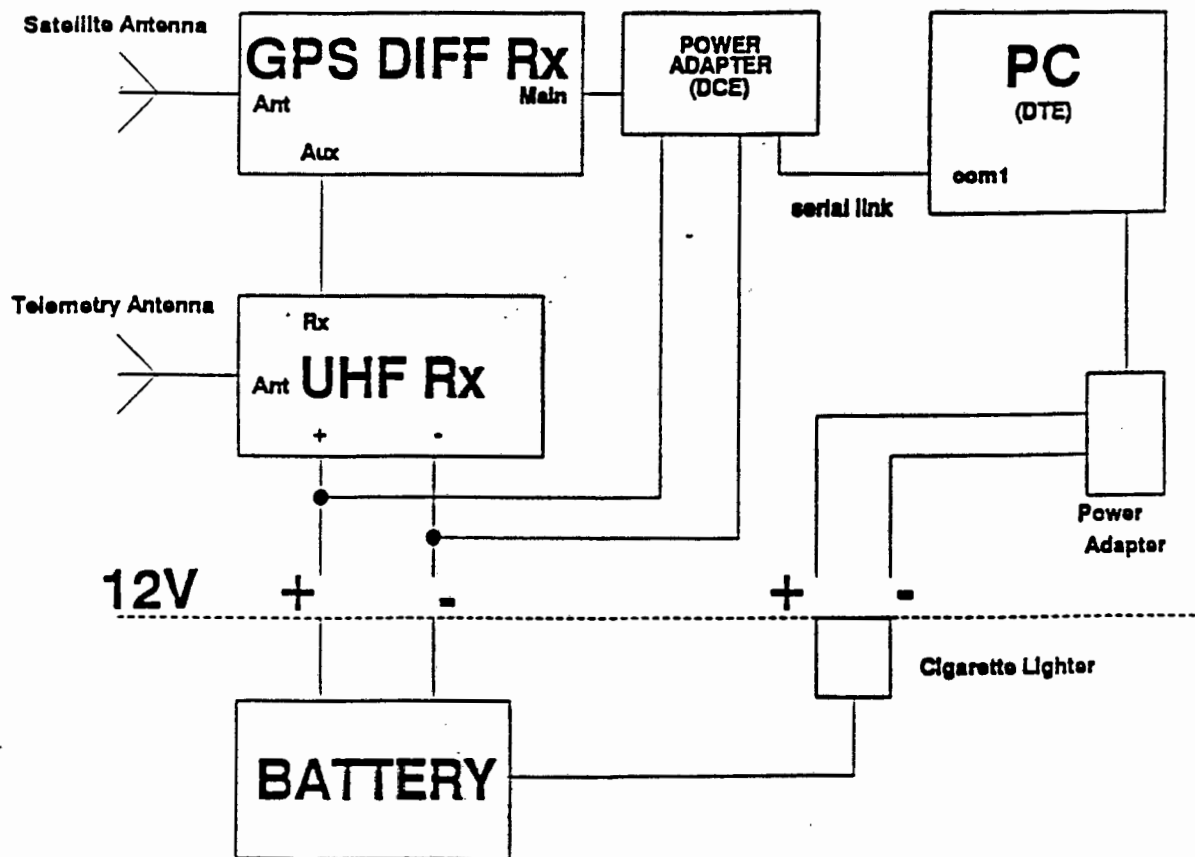


Figure 4.2: The hardware configuration of the mobile station on board the Land Rover

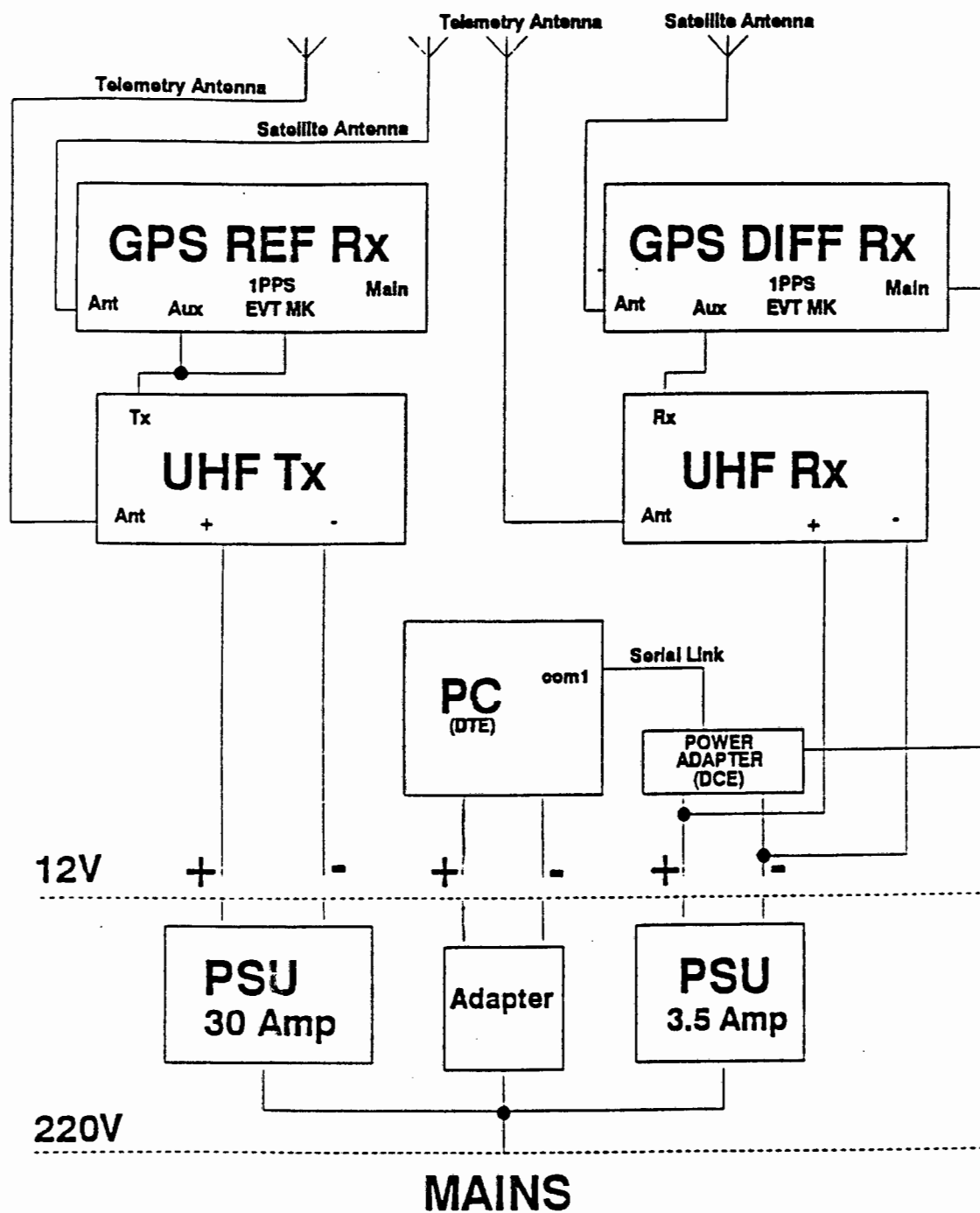


Figure 4.3: The hardware configuration for the static tests at the homestead

4.4 Field Test Description

The actual field tests took place from the 19th to the 26th April this year. Clear weather persisted throughout the duration of the tests. See Figure 4.4 (an aerial photograph scanned into and manipulated by GIS software), for all references to the various test places on the farm.

The rest of this section depicts the field tests that took place. The detailed descriptions of the events that took place can be found in Appendix C.



Figure 4.4: The Test Farm



Figure 4.6: Surveying in the 100m grid

a)

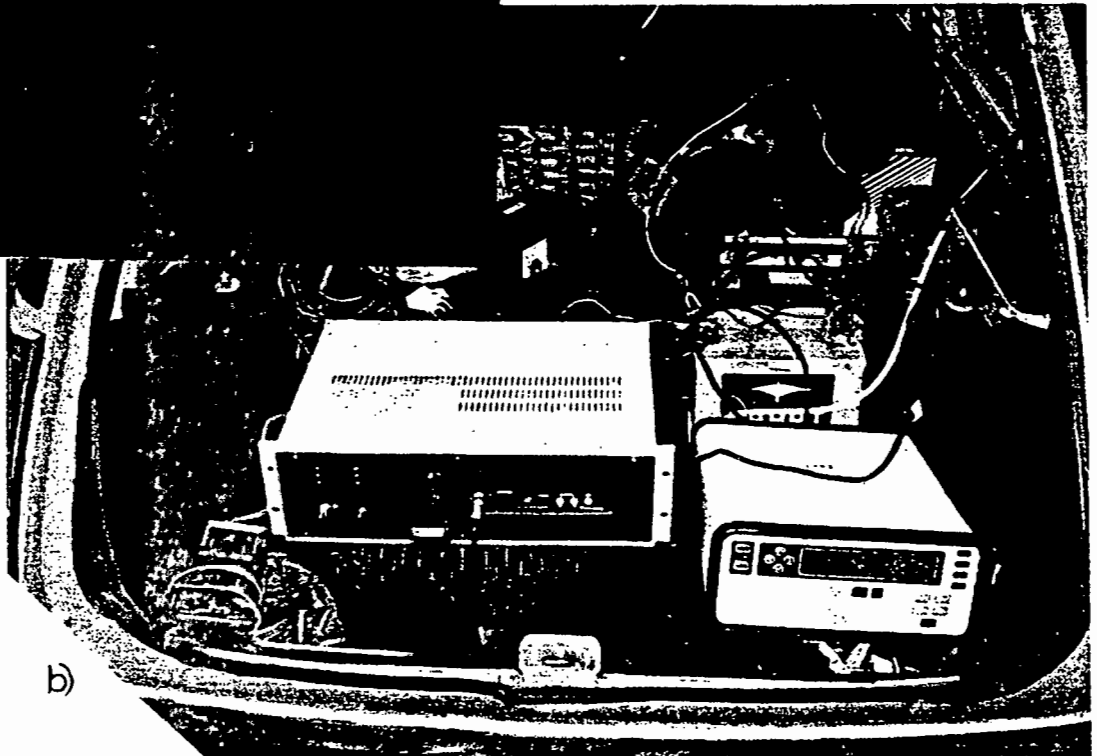
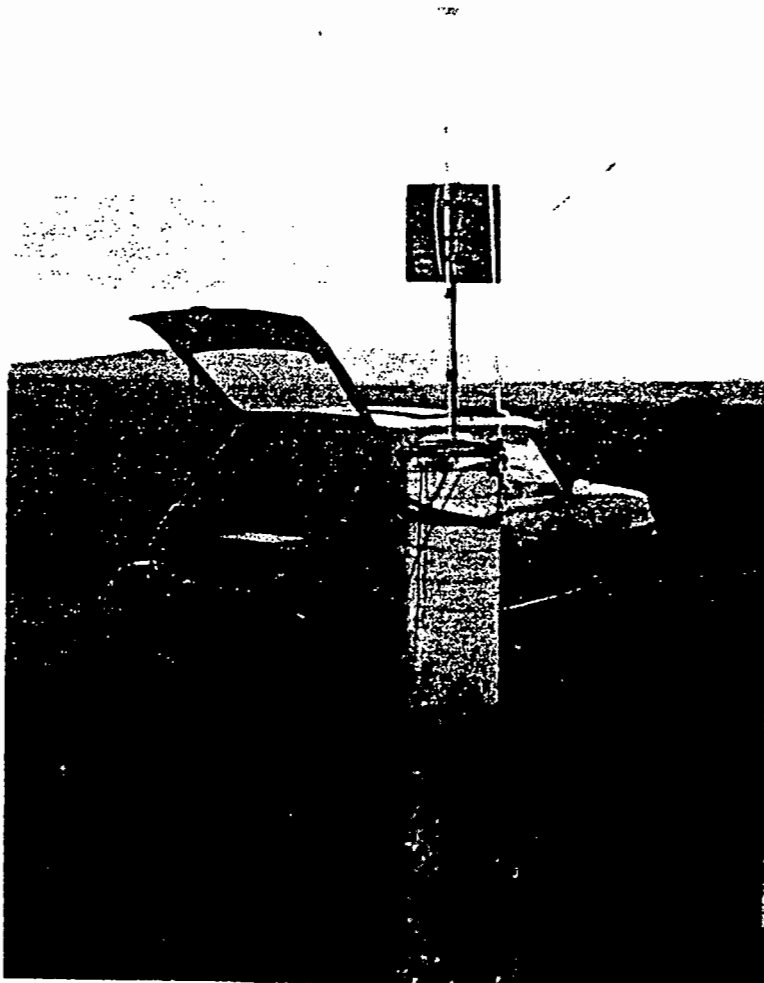


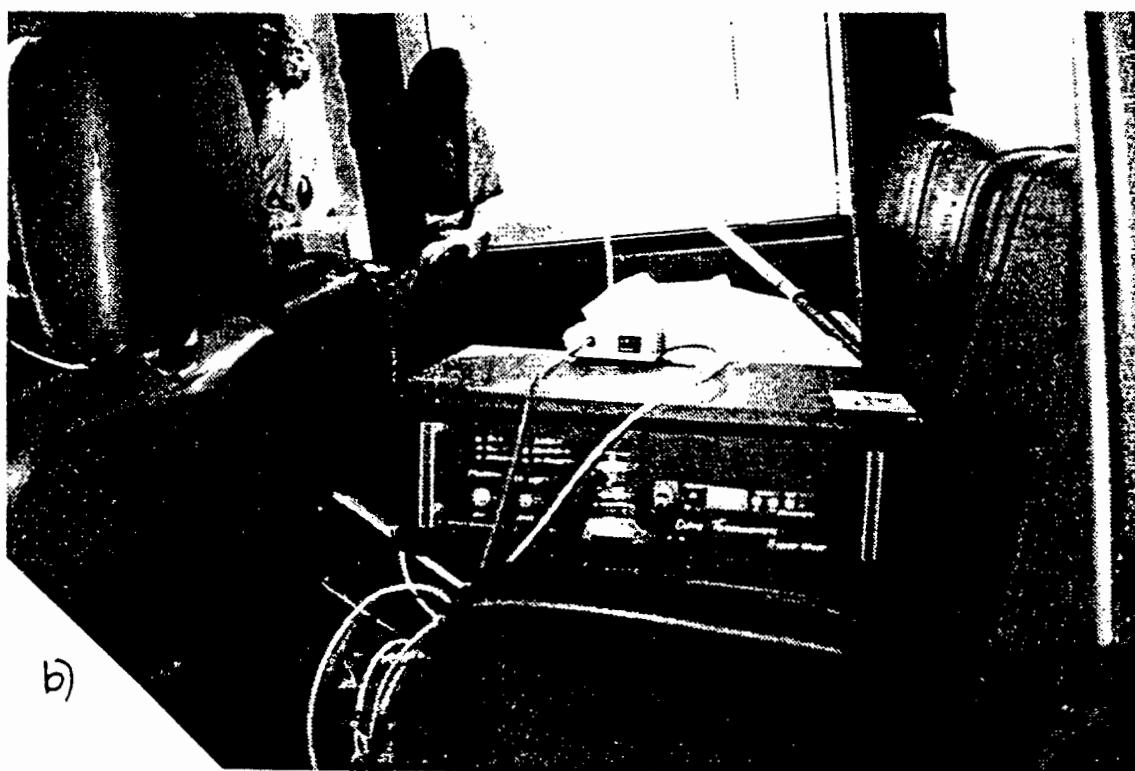
Figure 4.7: The reference station set up at the trig beacon: a) The trig beacon with antennae b) The GPS reference station with telemetry



Figure 4.8: The mobile station with the antenna attached to the Land Rover



a)



b)

Figure 4.9: The mobile station set up inside the Land Rover: a) The GPS differential receiver and notebook b) The telemetry antenna and receiver



Figure 4.10: The reference station powered from the generator



Figure 4.11: The sampling car with borer on its right hand side



Figure 4.12: Stakes were used to mark off sampling positions logged by dGPS

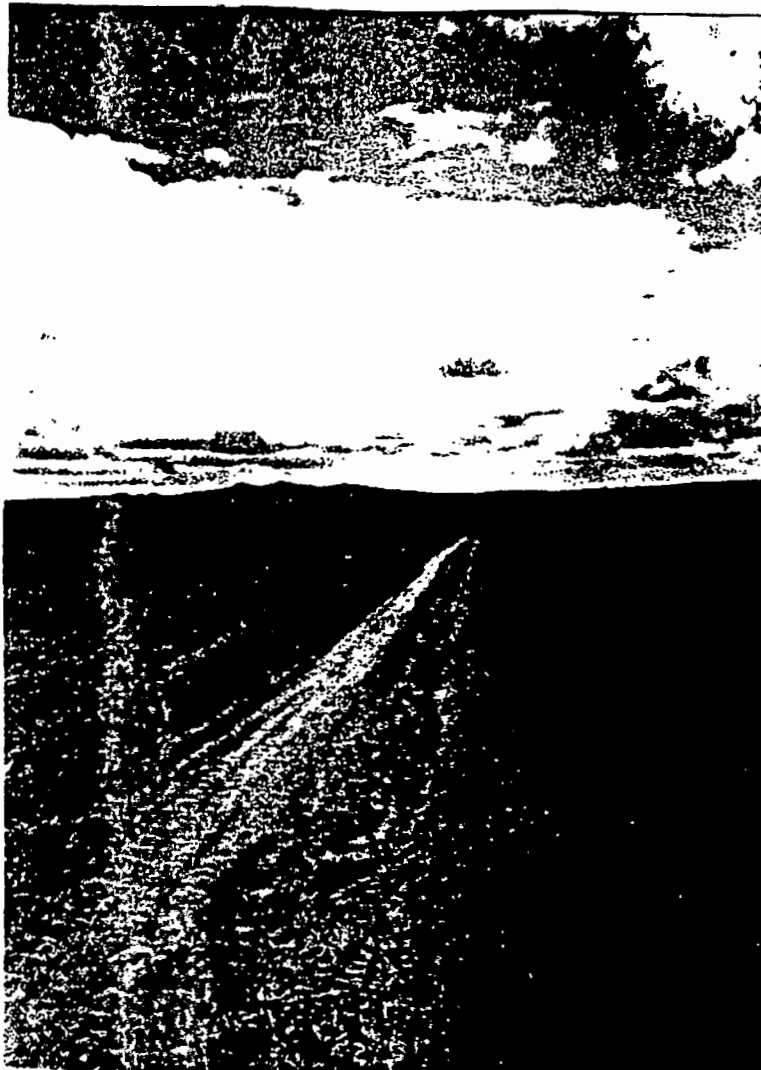


Figure 4.13: One un-flagged way-point marker on the road near to the trig beacon

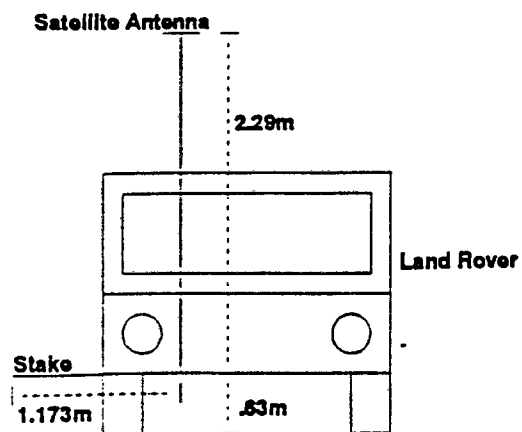


Figure 4.14: Configuration of the stake for the logging of way-points on the right hand side

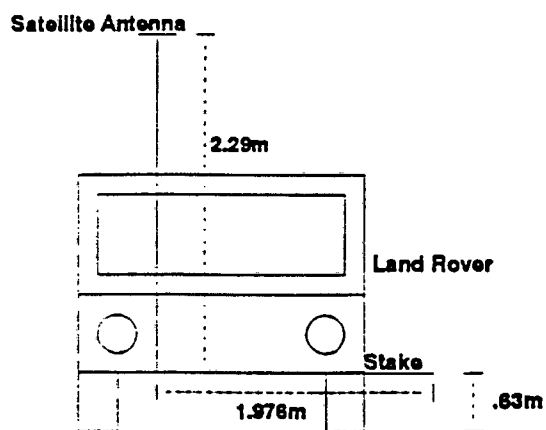


Figure 4.15: Configuration of the stake for the logging of way-points on the left hand side

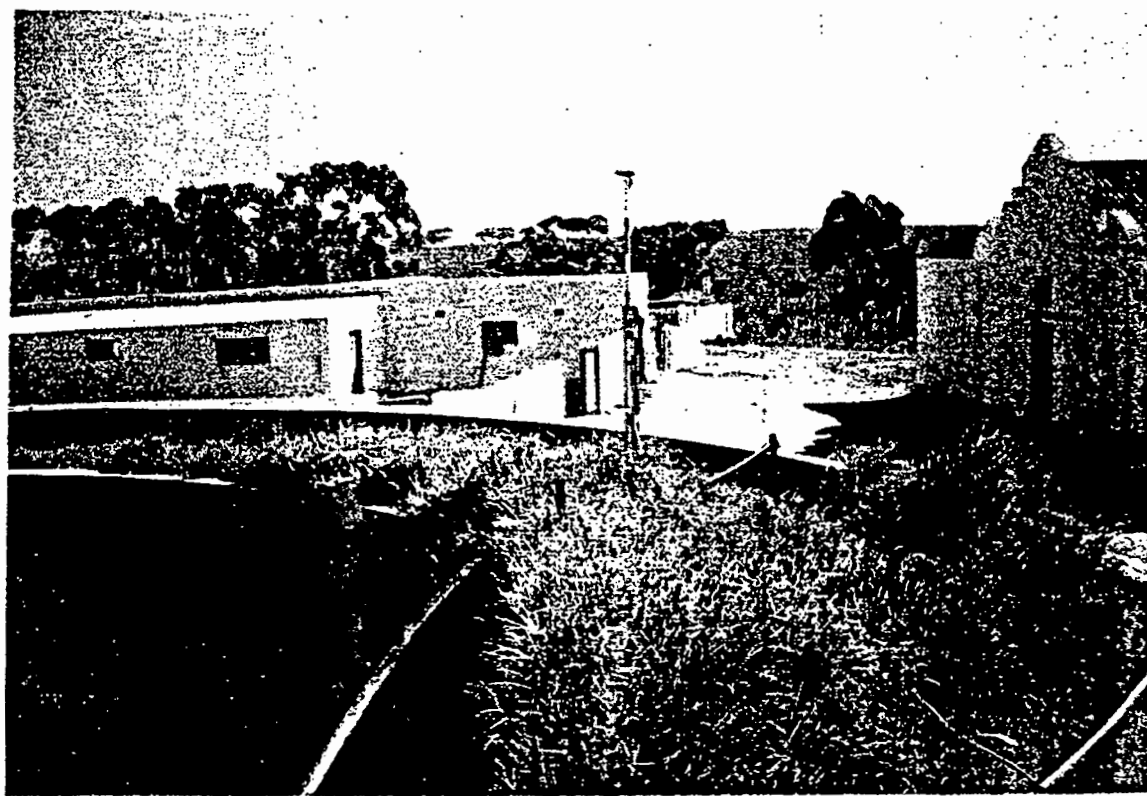


Figure 4.16: The reference station's satellite antenna set up at the surveyed position on top of the dam

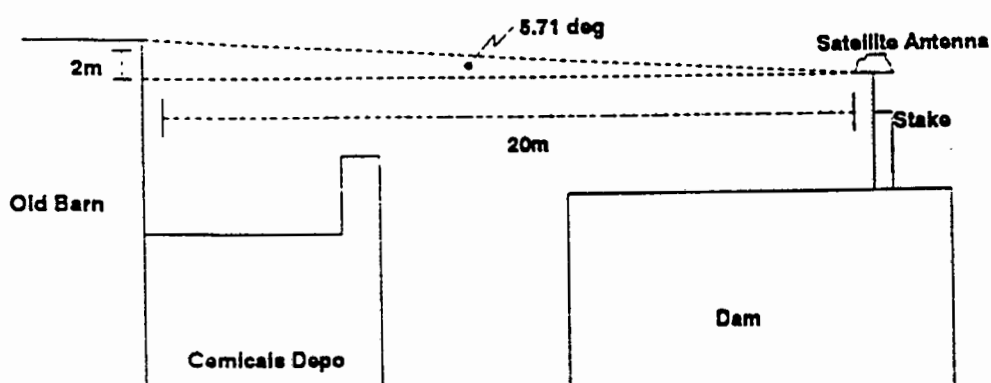


Figure 4.17: This figure indicates that the closest vertical obstruction falls within the masked angle (5°) programmed into the reference receiver

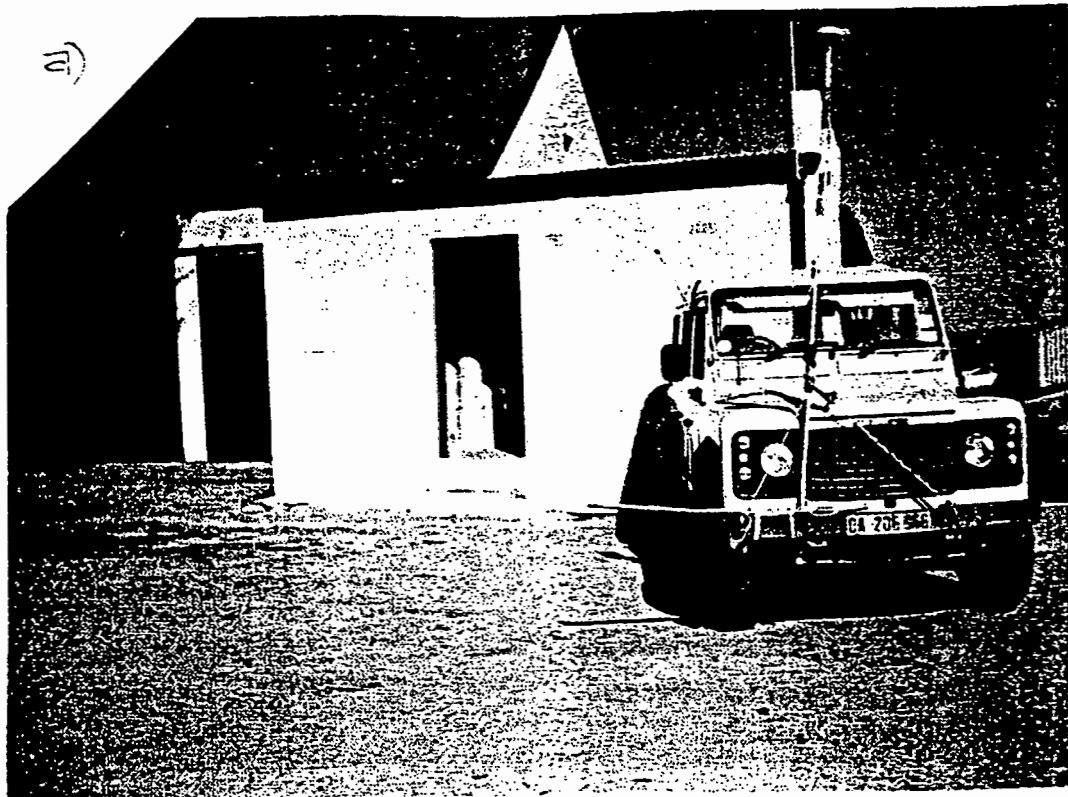


Figure 4.18: The reference station for the field dynamic tests: a) The room used to house the reference station also supplying mains power b) The equipment set up inside the room using the notebook to log the setup report

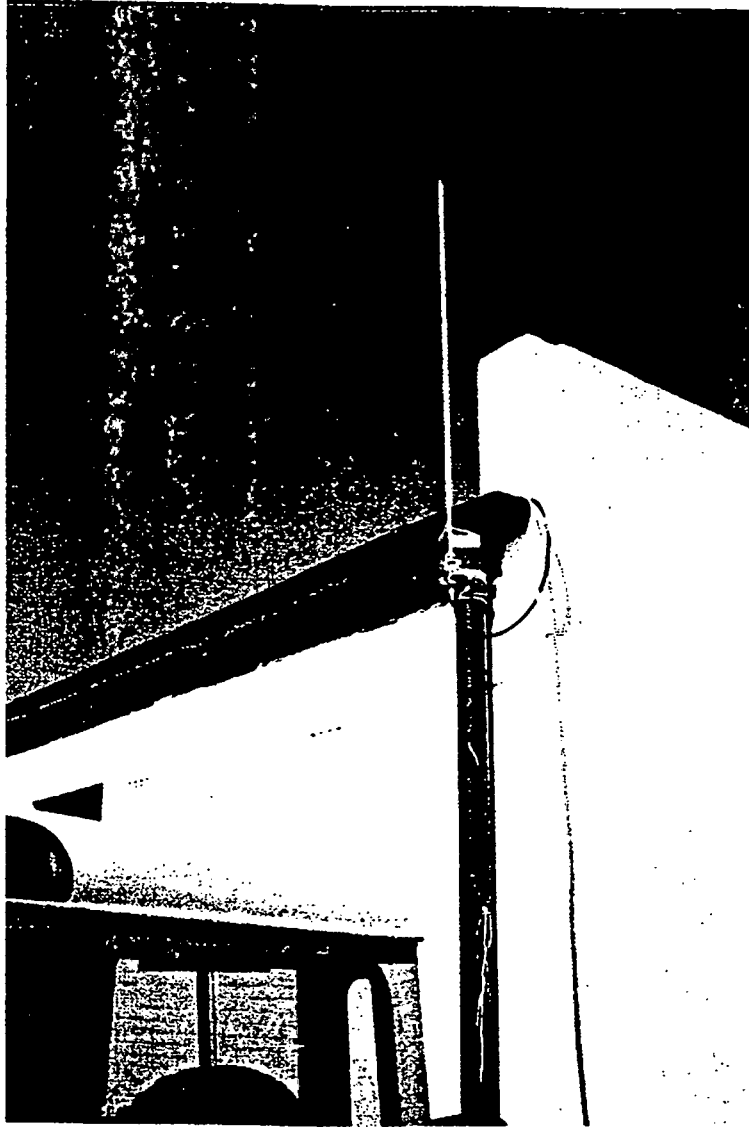


Figure 4.19: The telemetry antenna of the reference station



Figure 4.20: A horizontal stake was attached to the front of the vehicle for all the dynamic tests to serve as a reference for passing surveyed way-points

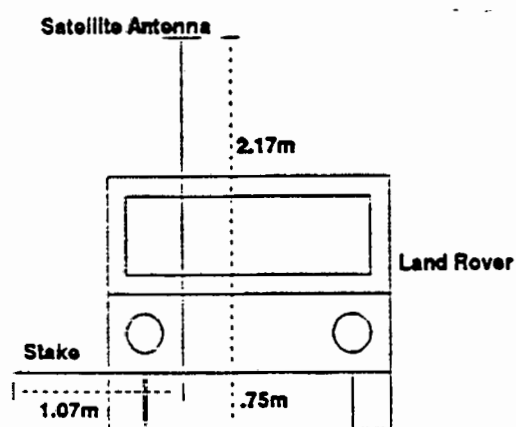


Figure 4.21: Configuration of the stake for the logging of way-points on the right hand side in the field



Figure 4.22: The reference and 'mobile' stations housed together for static tests



Figure 4.23: The reference and 'mobile' satellite antennae placed together at the same surveyed position for static tests



Figure 4.24: Going Home!

Chapter 5

Findings of Field Tests

This chapter depicts the observations made during the first set of field tests during which soil sampling and dGPS feasibility tests were carried out. To present the data in a meaningful way, software to simulate dGPS positions and process the data was used (See Appendices G.3 and G.2).

5.1 Differential Link (or DTL) and Terrain Dependency Tests

5.1.1 DTL and Multipath (MP) Effects

As already mentioned in Section 3.2.3, the best way to test whether the DTL is communicating the differential corrections is to have access to the differential corrections themselves. This was still ‘to be supplied’ (requested as an optional extra) as the Trimble manuals put it and was not available as a string (‘cyclic report’) from the receivers for these tests. It was found that the ‘d’ parameter in the position calculations cyclic report (See Appendix I for a copy of the position calculation cyclic report) represented whether the differential receiver was programmed to receive differential corrections or not and did not indicate whether the corrections for all the satellites in view were available.

It was possible in this case however, to invoke a ‘beep’ from the GPS differential receiver on receiving differential corrections from the reference station. Another indication during the tests and when displaying the logged data in the processing phase, was evident in the graphics of the plotted positions. If the positions ‘strayed’ whilst the vehicle was stationary or had a ‘jagged’ path when mobile, it

could be inferred that there were either loss of DTL or multipath effects at play.

During the differential link tests, in which the reference station was set up at the trig beacon (the recommended farm reference station), the GPS appeared never to lose the link at all spots marked with a cross in Figure 4.4 where position measurements could be taken (beeping continuously at the receivers 'sync' rate).

There was one exception at the region marked by a square, in which neither the GPS receiver sounded the receipt of corrections nor did there seem to be any response from the UHF receiver. The link was easily restored however, by simply attaching the omni antenna outside the vehicle and a little higher.

During the terrain dependency tests, whilst using the 'dynamic tests' software option of the test software, the display indicated loss of DTL at the point marked with a diamond. Figure 5.1 indicates how the plot of positioning information strays from the static position of the vehicle before it receives correction data from the reference station and 'snaps back' to the correct position. These results were confirmed by the infrequent 'beeps' of the GPS receiver. The UHF receiver never seemed to stop receiving signals but was obviously not properly receiving the full dGPS corrections for most of the correction updates. These results were also obtained whilst the reference station was still set up at the recommended reference site (the trig beacon). It was concluded that these results were definitely due to loss of DTL and not to multipath effects (it was a relatively open area) or loss of lock with the satellites (the logged data indicated that 4 satellites at least were in sight and the positioning data was still visible on the graphics screen: the latter was programmed to disappear due to the dynamic test software design when satellite lock was lost).

Logged horizontal velocities indicated around $.45m/s$ whilst the position information was straying and $0m/s$ when it snapped back to the static position.

Moving from this position into the trees, the DTL was re-established before passing through a gate and moving amongst the trees. Figure 5.2 indicates the logged positions in moving through the gate and into the trees up to the point before satellite lock was lost. The red line indicates an idea of the actual path taken. Figure 5.3 plots the rest of the logged positions but will be explained in the following discussion of satellite lock terrain limitation effects. This data represents loss of DTL or multipath effects in a 'moving' application. At the point marked in purple, for example, there was a bearing change of 16 degrees and a velocity jump of $1.1m/s$ in $1s$ (i.e. a ridiculous acceleration of $1.1m/s^2$). These results are compared with a $.15m/s^2$ acceleration occurring in the region marked in yellow when the vehicle accelerated to $8m/s$ with full dGPS corrections being received. These latter results represent typical vehicle accelerations at typical vehicle speeds with the *dGPS* errors included.

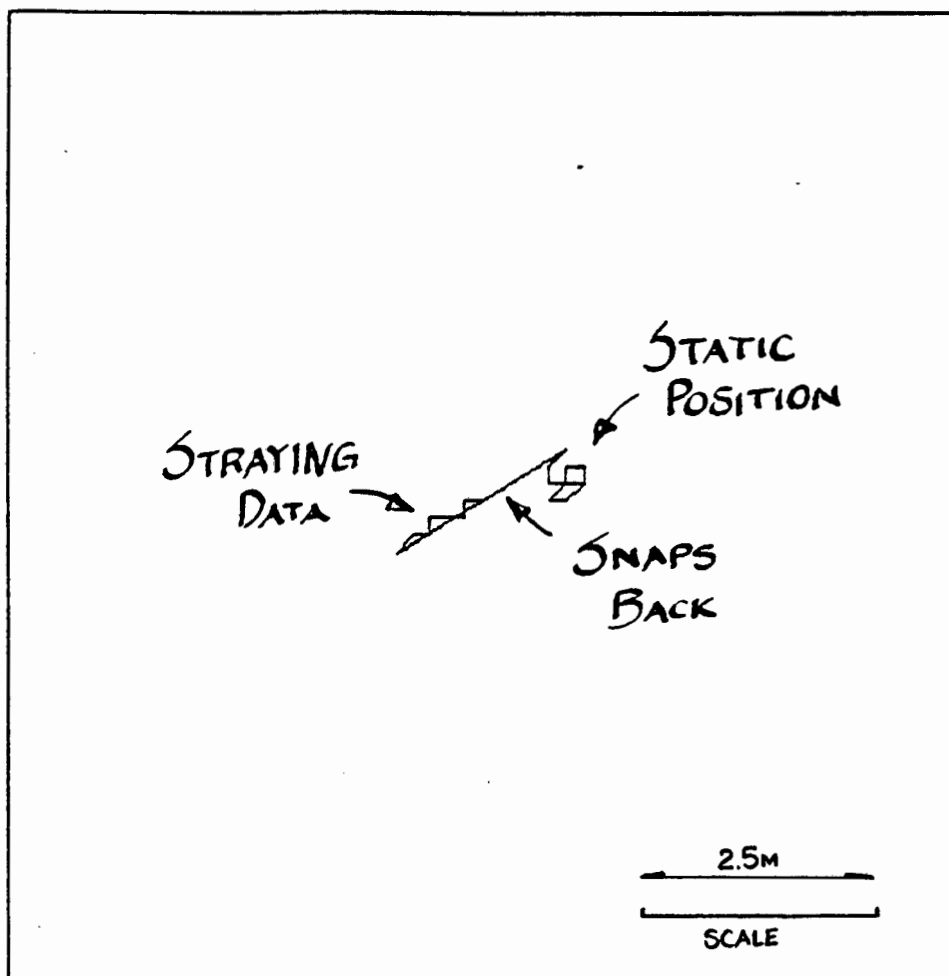


Figure 5.1: Loss of DTL at a static position

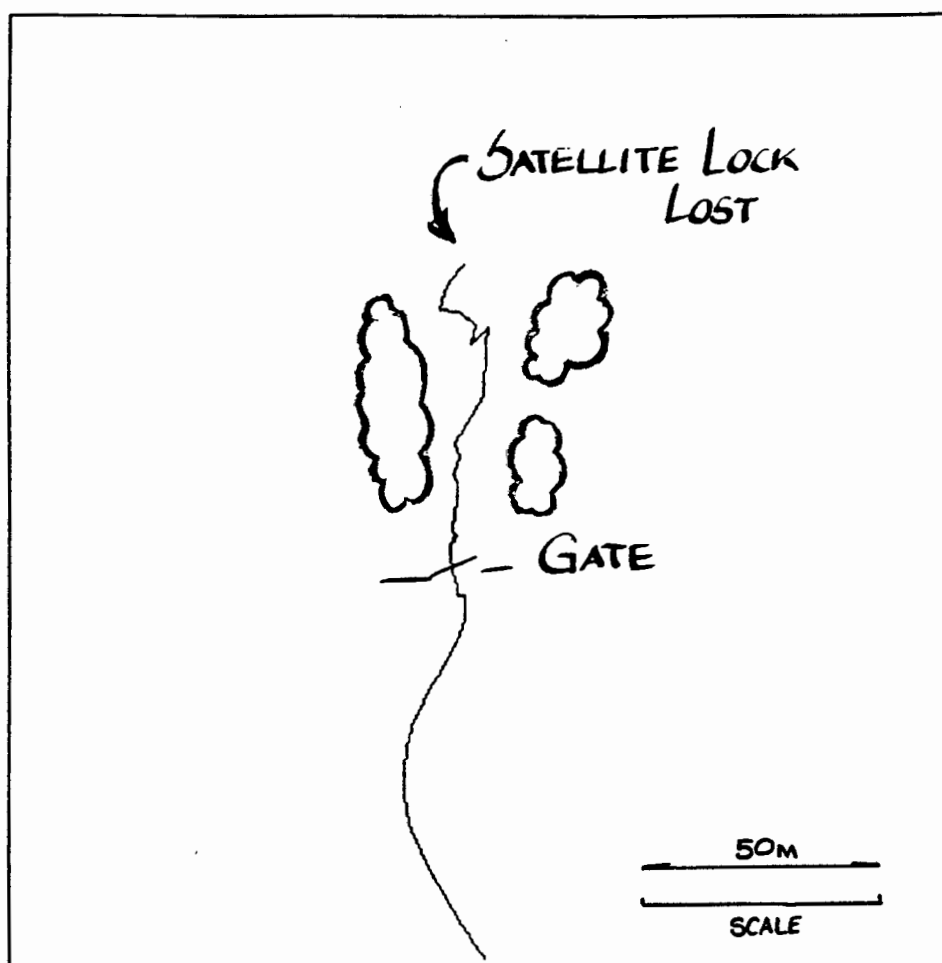


Figure 5.2: DTL or MP effects before loss of satellite lock occurred

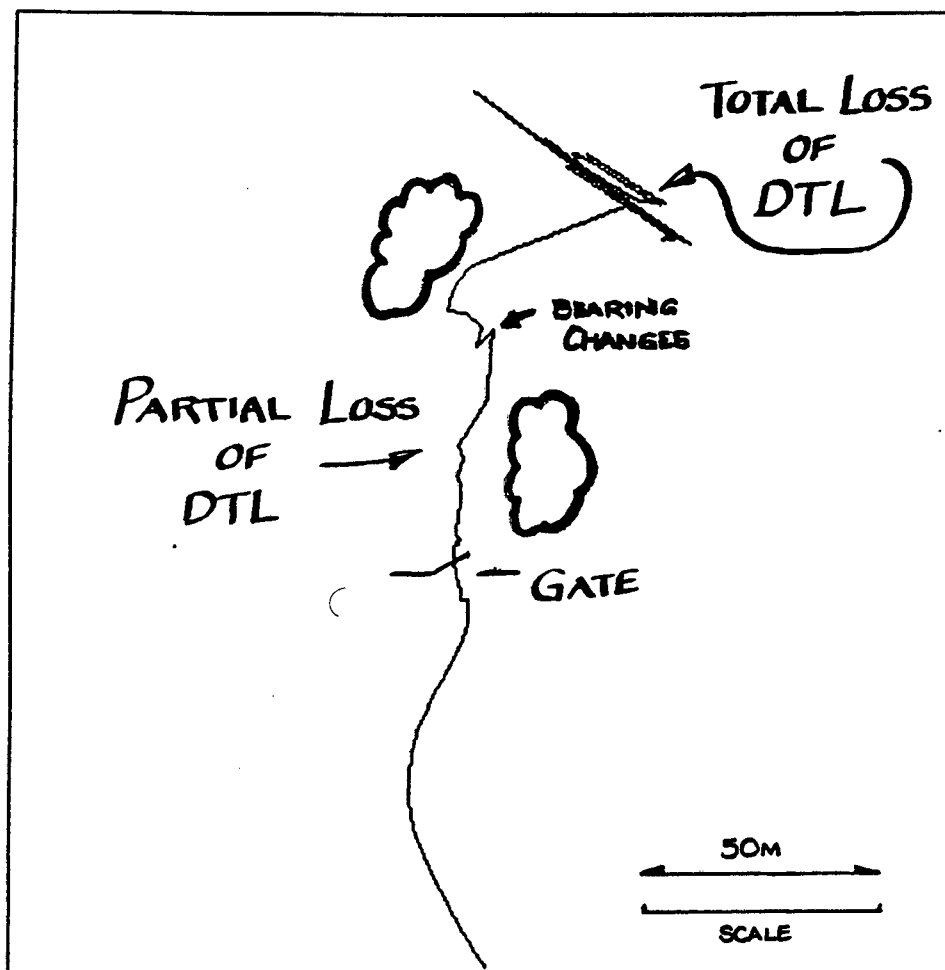


Figure 5.3: Terrain effects on vehicle path

It is worth noting a final observation with regards to the DTL; no loss of DTL occurred (no 'jagged routes': See Figure 5.18 in Section 5.5) whilst doing the 'dynamic field tests'. It is true that for these tests the reference station had been moved to the homestead to take advantage of the mains power, but based on the results of the differential link tests at the extremities of the farm area, it can be concluded that there should be no loss of DTL problems within the cultivated fields of such a farm.

5.1.2 Means of Detecting Loss of DTL/MP

Due to the possibility of obtaining differential correction data at the mobile station, details of other parameters that can be used to detect loss of DTL will not be examined in great detail. In the static case, however, velocities out of the range of typical static straying velocities (produced by correct dGPS operation) could be used to indicate GPS stand alone operation (loss of DTL). Alternatively, accuracy calculations on the previous position measurements could be made and the standard deviations of dGPS vs stand alone GPS compared for DTL operation inference.

In the 'moving' case, more sophisticated techniques would have to be employed to detect loss of DTL or MP effects if the receiver did not produce a string of differential corrections. Having either access to a vehicle speed indication or knowledge of typical vehicle speeds and normal velocity errors induced by dGPS, inappropriate velocities, accelerations or bearing changes could be used. Another possible option for the determination of loss of DTL effects in the moving application, would be to fit a best fit curve to the previous position data in real time and determine whether the residuals fall outside those of typical dGPS operations at typical speeds and accelerations.

5.1.3 Loss of Satellite Lock Effects

The differential receiver was very kind in providing information relating to the loss of satellite lock with the 's' parameter of the position calculation cyclic report becoming zero when 3 or less satellites were in view. This was for the case when the receiver was programmed to provide 3 dimensional position information. The 's' indicator would also indicate zero when 2 or less satellites in view in the case of 2 dimensional position requests, and so on.

Using the dynamic test software option of the test software loss of satellite lock only occurred once in the test field during the dynamic tests. This was when the

Land Rover was driven close to the fence (an uncultivated zone) next to some trees and is indicated in Figure 5.4. Figure 5.5 indicates a typical vehicle path in the field as it rounds a contour with no loss of satellite lock as it passes the trees.

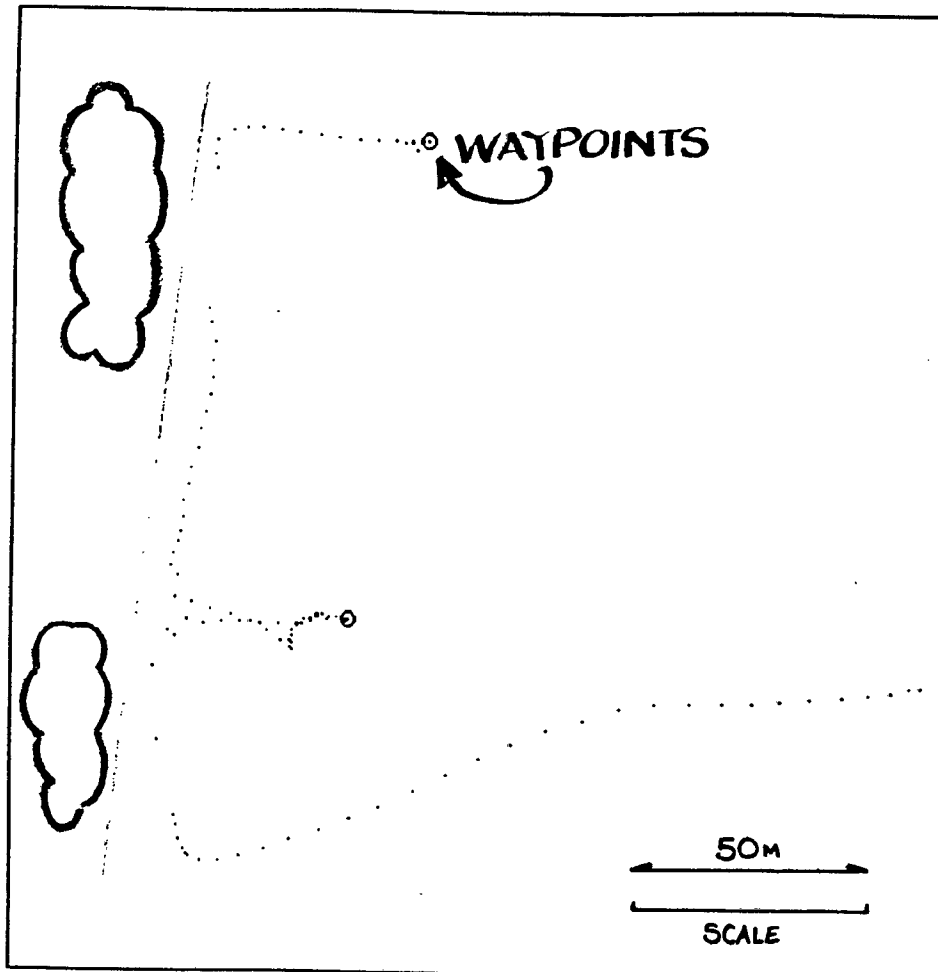


Figure 5.4: Loss of satellite lock in the test field

Other places where loss of satellite lock was encountered in the terrain dependency tests using the dynamic test software option were :

- Along the Occultdale Road labelled in Figure 4.4. Figure 5.6 marks the points at which satellite lock was lost due to the neighbouring trees in red and an idea of the true path in blue.
- Along Adderley Road the full reception from the satellites faltered from 6 in view to 4 in view but loss of lock never occurred lost. See Figure 5.7.

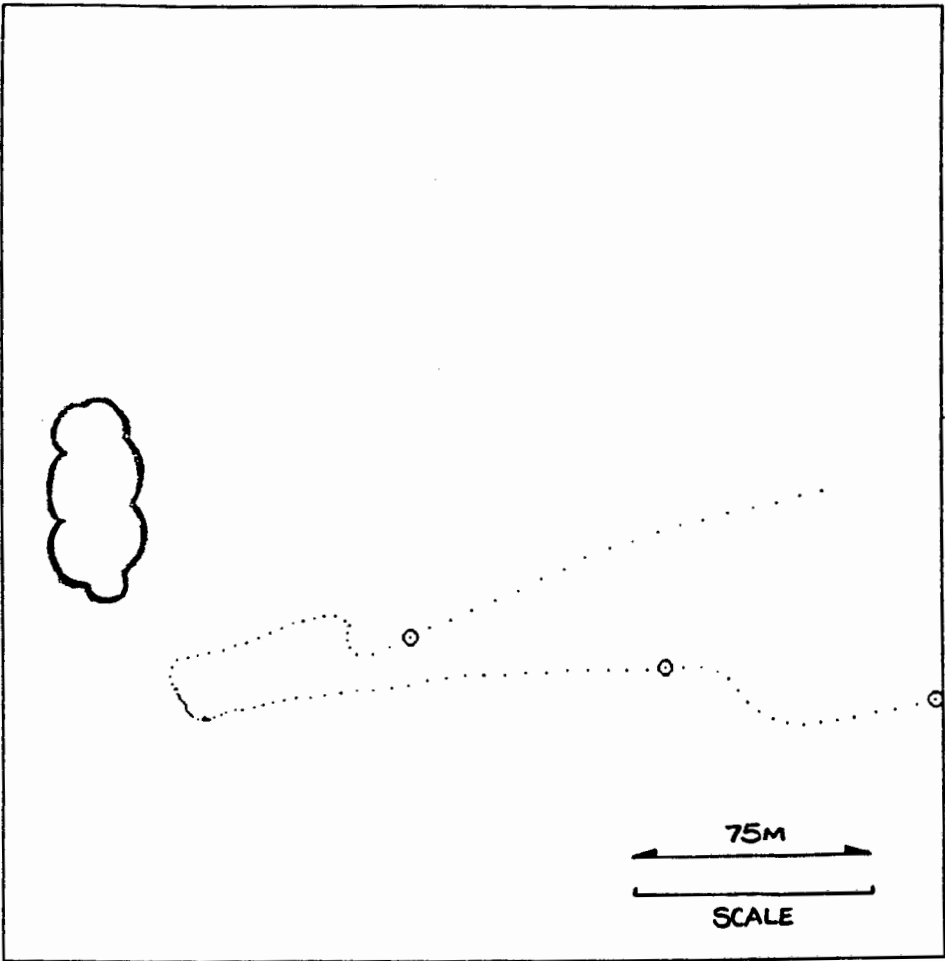


Figure 5.5: No loss of satellite lock on a typical route past vertical obstructions in test field

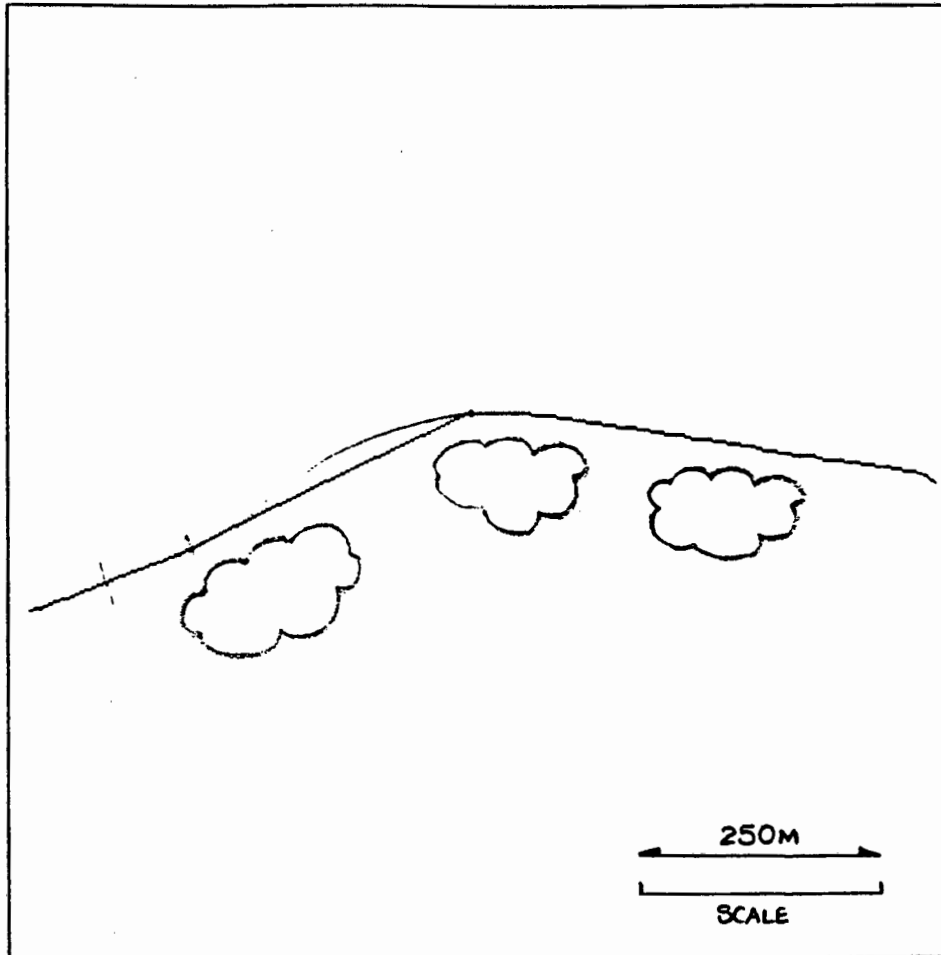


Figure 5.6: Loss of satellite lock on the Occultdale Road

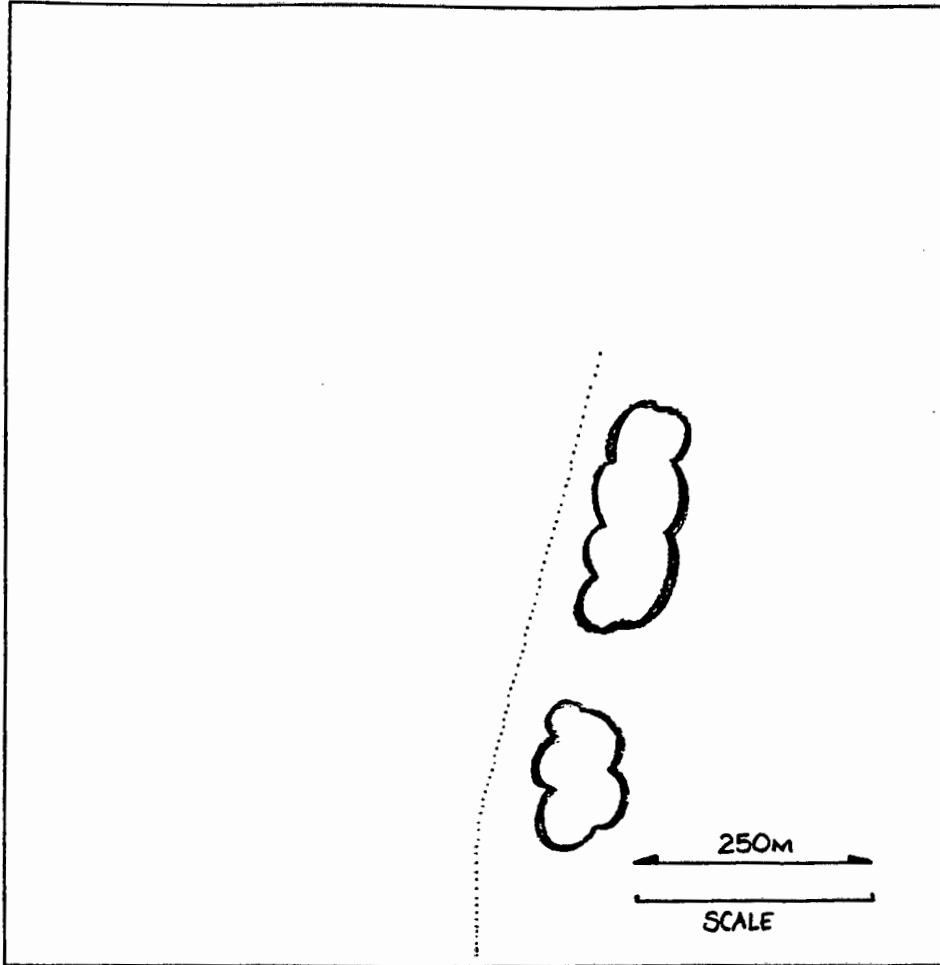


Figure 5.7: Loss of satellite lock test on the Adderley Road

- As mentioned before, the area marked by a diamond in Figure 4.4, next to the Alexandria homestead, indicated loss of lock with the satellites at a certain point in the trees. An exploded view of this is shown in Figure 5.8 in which satellite lock was lost for a bit before being restored. The remaining confusion in the plot was due to loss of DTL effects in the moving application. The diagram in green indicates the actual path the vehicle took.

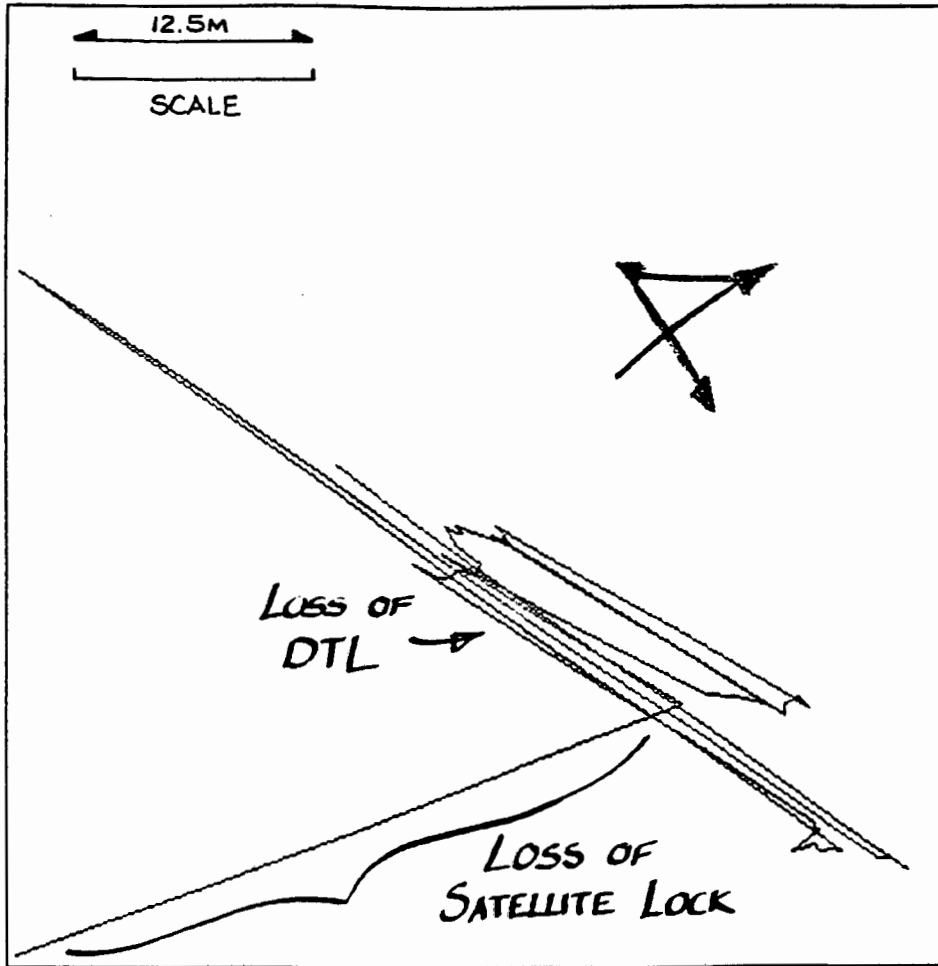


Figure 5.8: Loss of satellite lock in the trees near Alexandria

5.2 Standard Receiver Tests

Information relating to the satisfactory working of a GPS receiver, can be deduced simply from observing its display of operation at various levels. What was

observed was that no information from satellites below the mask angle was included in the position solution. For example, in one observation, satellite 'PRN' number 27 was not included in the solution at an elevation of 4° with a mask elevation of 5° . On viewing the satellite information however, the receiver appeared to be able to track the satellites right down to the horizon (for example, one observation of a detected satellite elevation of 3° confirmed this).

The credibility of the receiver in not implementing smoothing algorithms to disguise poor position calculations (illustrated by jagged route plots), is adequately illustrated in Figure 5.18. This plot illustrates some tight corners made at fairly high speeds not being 'cut off' due to a smoothing algorithm.

For the test in which it is determined whether the receiver is calculating positioning information more slowly than is indicated by the specified position update rate, a program was written to display and log the positioning information on approaching a stopping point. This program provided the facility to plot a finishing line and observe the overshoot and is available in the test software provided in Appendix G.1. The test in which the 'finish line' was approached slowly before stopping was plotted by the post processing software and is shown in Figure 5.9. This plot shows the very small overshoot that occurred as expected in this test.

Figure 5.10 plots the overshoot that occurred in the event of a sudden stop. The test was repeated at a slightly faster speed and is shown in Figure 5.11. The first line drawn in the plots indicates the finish line reference. The second line indicates where the vehicle actually stopped and was calculated from an extrapolation of the finish line endpoints by its equivalence in degrees in the direction of the approach bearing. In the first case it was 58cm and in the second 45cm. The overshoot in the first test represents a distance of about half a metre and in the second of about a metre.

These results are in line with what you might expect of an actual position calculation rate (synchronizing rate) equal to or better than that of the position update rate requested by the programmer (1s in this case). This can be better explained in a diagram (See Figure 5.12) and is in reference to the theory expressed in Appendix J.

The figure indicates that in the event that positions were actually calculated every 2 seconds with a requested position update rate of one second, every alternate position output would be a guess based upon an extrapolation of the last position fix. In fact, according to the theory, the receiver may only have registered that the vehicle has stopped 3 seconds after the event resulting in 3 seconds of incorrect information. In the case of Figure 5.11, that could mean an overshoot of about 27m.

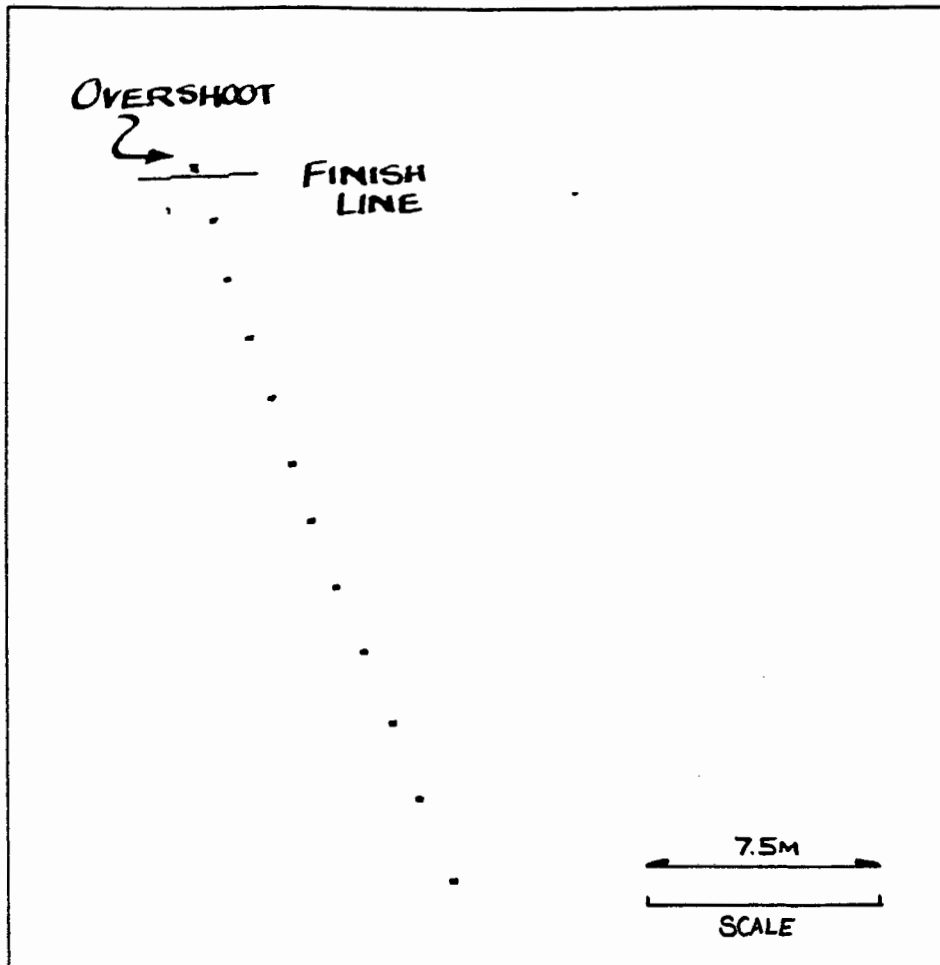


Figure 5.9: Overshoot caused by a slow approach to a stopping point

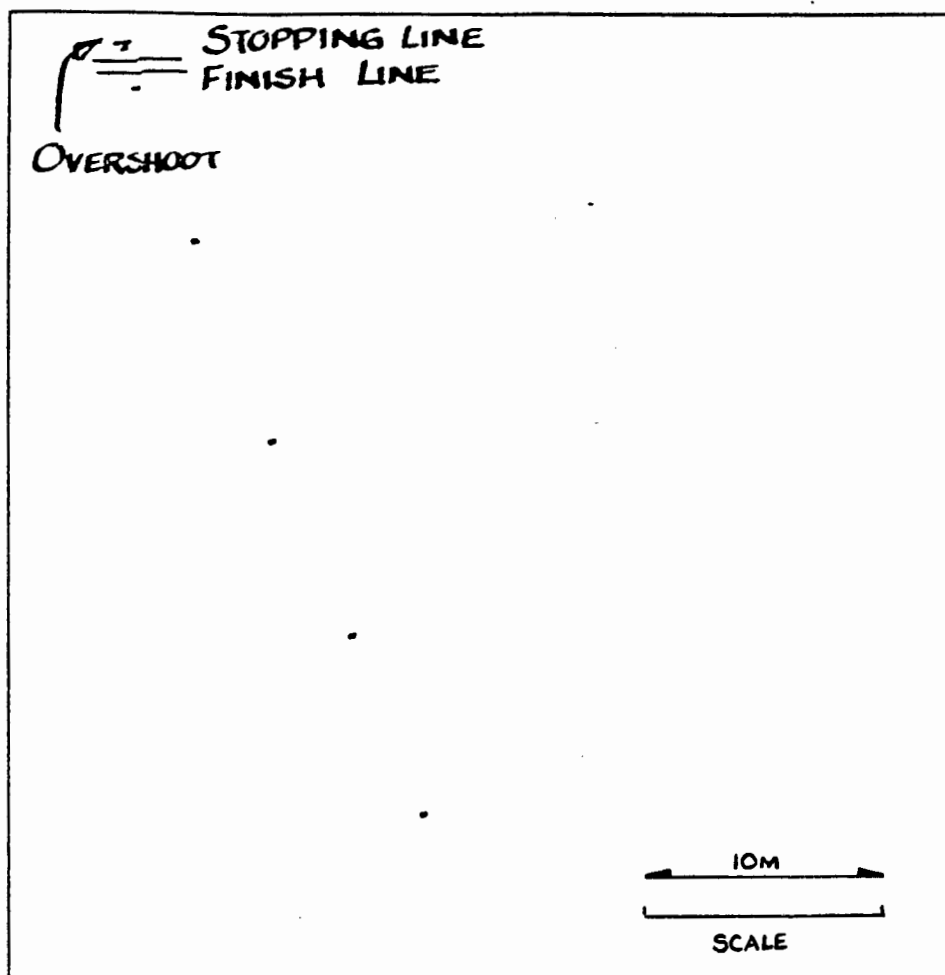


Figure 5.10: First overshoot caused by a fast approach to a stopping point

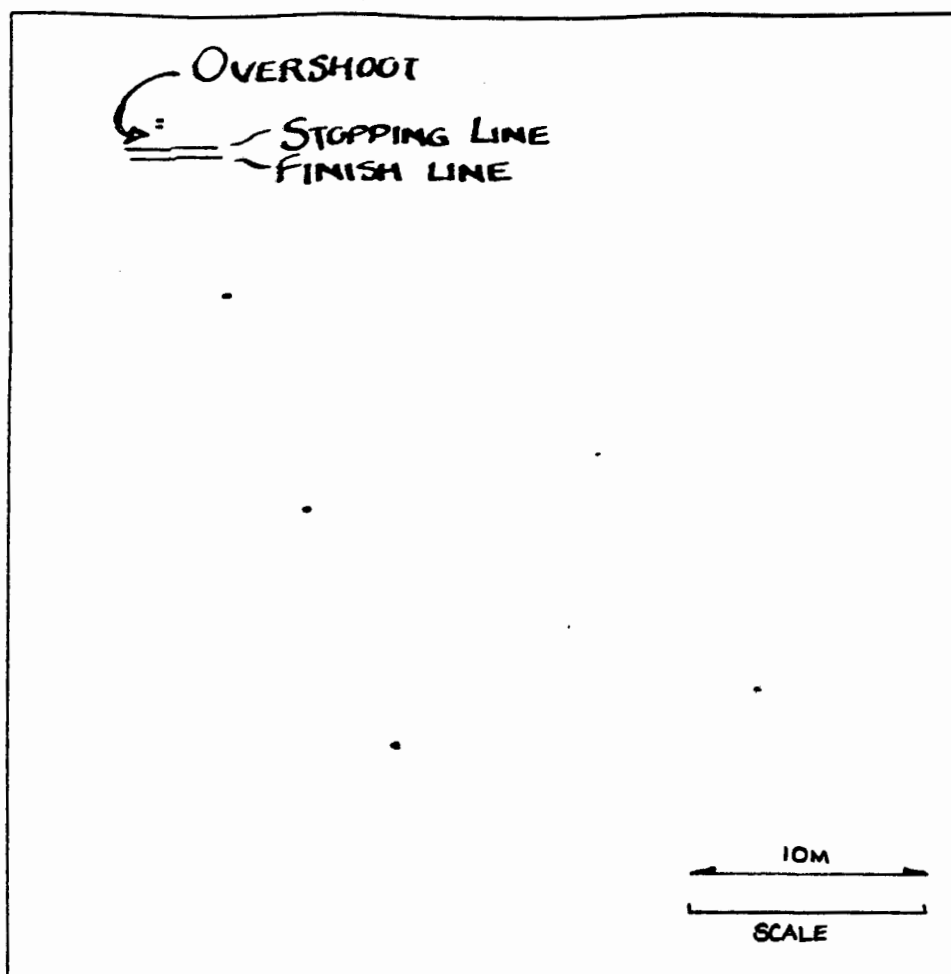


Figure 5.11: Second overshoot caused by a fast approach to a stopping point

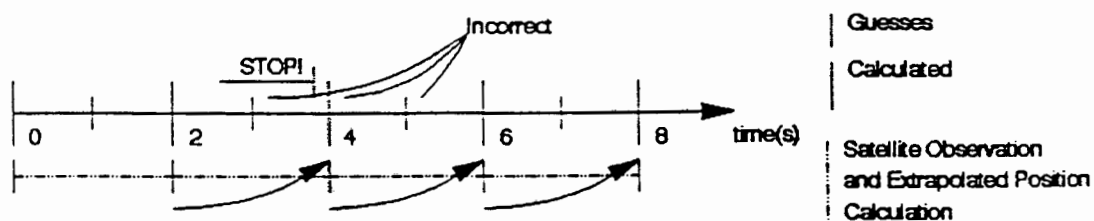


Figure 5.12: Explanation of the overshoot occurring at poor position calculation speeds

5.3 Static ‘Mobile Station’ Test

As described in Appendix C, the motivation for doing this static test was twofold. The first was to determine the current limitations of the GPS technology in terms of its reliability and accuracy. The second was to evaluate which parameters predominantly effect its accuracy and at which levels the accuracy becomes unacceptable as a means of real time detection of positioning information integrity.

Accuracy determination could be done two or three dimensionally. Unfortunately the positioning information from the GPS receivers is in geographical co-ordinates (lat. and long.) and height is in meters above the ellipsoid. The data had to be converted to metres so that 3 dimensional positioning accuracy could be determined according to the formula:

$$s = \sqrt{\frac{\sum_{i=1}^n [(x_i - \bar{x})^2 + (y_i - \bar{y})^2 + (z_i - \bar{z})^2]}{n - 1}} \quad (5.1)$$

The XFORM package from Prof Merry could not do a conversion of the lat./long. positions to metres (geographicals to gauss conform) for the 8MB file of static data. To test the linearity of the XFORM transformation at the static point and over the range of the position scatter, it was decided to do the transformation at the static position’s calculated mean and at the distances one standard deviation (in degrees) away from the mean. With this data it was hoped to determine an approximation of the slope of the transformation function at the mean. This was done, and in testing it at distances of two standard deviations away from the mean (in lat. and long.), the linear approximation produced maximum errors of 1mm compared to those values calculated by the transformation itself. This is a sign of suitable linearity considering the transformation process often produced discrepancies of the same order. Anyway, the calculated slopes provided a means of converting the position information to its equivalent in metres and was accurate enough to be used in both the 2 and 3 dimensional accuracy approximations (see the associated processing software in Appendix G.2).

The 2 dimensional standard deviation (σ) of the receivers position represents the positioning accuracy in a horizontal plane and not on the surface of the field. In cases where there are steep field gradients, the field slopes should be taken into consideration in the calculation of σ . For these test fields however, this will make a minimal amount of difference over these σ values. The 3 dimensional calculation of σ is indicative of the effects and uncertainties associated with the calculation of height information. For the fertilizer application project however, we have no real interest in 3 dimensional σ values.

A plot of the position scatter about the static point is represented in Figure 5.13 and the numerical results will follow in Figure 5.14:

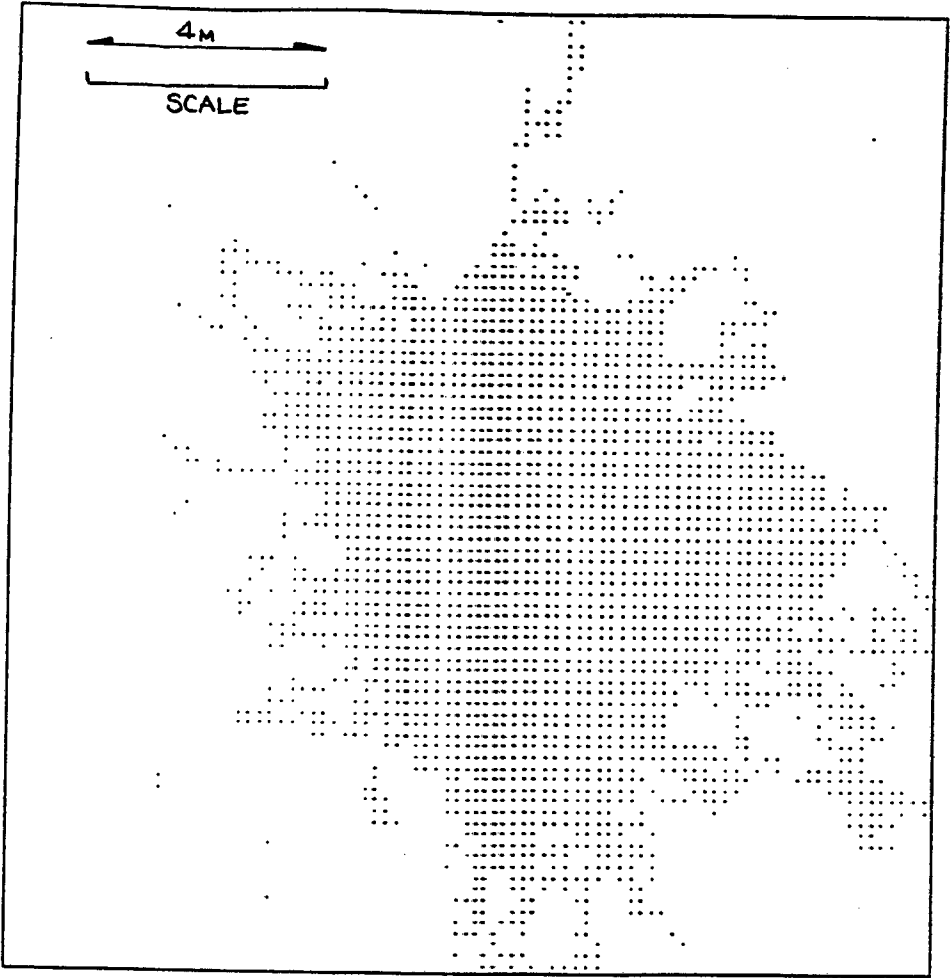


Figure 5.13: Scatter pattern of statically logged positions

The major measurable parameters affecting positioning accuracies are the position's Position Dilution of Precision (PDOP indicating the geometric quality of the position fix) and the number of viewable satellites.

In Section 2.2.3, it was shown that PDOP is obtained from the residuals of the least squares solution of the over-determined set of equations obtained from all the satellites in view. In other words, in doing these required matrix operations, *all* the satellites in view are used to calculate PDOP. Intuitively then, if it had been that the PDOP was determined from the four best choices of all the satellites in view, then for all the time that four satellites or more were in view, accuracy would be directly proportional to PDOP (i.e. for a few perturbing misrepresentations of the ionosphere compensation model, uncorrected effects of SA, ephemeris

miscalculations etc.). As this is not the case, the number of satellites is another variable which effects the accuracy calculation significantly. For example if there are 3 or less satellites in view, then no matter how good the PDOP, it will not be possible to determine the position 3 dimensionally. Similarly, if eight satellites are in view, but are all close to the horizon, then simply by virtue of the solution being heavily over-determined, it will be better than expected with such a poor PDOP. In conclusion, accuracy is a complex function of the number of satellites and PDOP and other unmeasureable effects. It cannot therefore be expected to find an absolute consistent limit to these parameters to be used as a warning for poor accuracies. The results shown in Figure 5.14 were obtained however to provide a guideline as to what these limits could be estimated to and to provide an indication of the accuracy and reliability of the technology.

THESE WERE THE OVER-ALL RESULTS :

PROCESSED :

MEAN LAT : -33 42.117482S
MEAN LONG : 18 38.091494E
MEAN HEIGHT : 102.44M
CORRECTED MEAN HEIGHT : 95.93M
STD. DEV. (2D) : 2.22M
STD. DEV. (3D) : 4.31M
MEAN PDOP : 2.69
PDOP STD. DEV. : 1.14
AVERAGE No. OF SATELLITES : 6.03
NUMBER OF RECORDS : 84825

SURVEYED :

LAT : -33 42.117367S
LONG : 18 38.091503E
HEIGHT : 94.48M

FILTERED RESULTS :

PDOP FILTERS :

	RECORDS IN			
	RANGE 1	RANGE 2	RANGE 3	RANGE 4
MEAN PDOP	2.1709	3.086	4.351	7.527
STD DEV	1.981	2.316	2.213	4.859
% REC	59.9	34.9	2.4	2.6

RANGE 1 :	< Mean
RANGE 2 :	Mean <> Mean + PDOP Std Dev
RANGE 3 :	Mean + Std Dev <> Mean + 2(PDOP Std Dev)
RANGE 4 :	> Mean + 2(PDOP Std Dev)

NUMBER OF SATELLITE FILTERS :

	RECORDS IN					
	RANGE 1	RANGE 2	RANGE 3	RANGE 4	RANGE 5	RANGE 6
SATELLITES	2.83	4	5	6	7	8
STD DEV	3.05	3.413	2.66	2.14	1.735	1.76
% REC	0.06	2.6	25.9	42.5	23.1	5.6

RANGE 1:	< 4
RANGE 2:	=4
RANGE 3:	=5
RANGE 4:	=6
RANGE 5:	=7
RANGE 6:	=8

Figure 5.14: Table of results of static test

The reason why the height had to be corrected in the static results is because the reference data was incorrectly programmed into the reference station (see Appendix H: 101m entered instead of 94m). This appeared to add an offset onto all the height measurements, but didn't appear to effect the geographical co-ordinates and will not affect the height accuracy (or 3 dimensional accuracy) calculations.

The PDOP results indicate the dependence of accuracy upon the geometric quality of the position fix however not in a perfectly linear fashion. This could be due to the fact that other variables are at play in the determination of these results (as discussed above), or could be the result of the small data sets representing certain ranges (Range 3 for example). Similar comments can be made in the case of the 'number of satellites' results (Range 6 for example). In the case of less than 4 visible satellites, the curious result of a standard deviation better than that obtained with 4 satellites could also be due to the fact that only 0.07% of the records represent this occurrence. The receiver also had the characteristic that it held the position account at the last position calculated with 4 or more satellites until it could again calculate a position 3 dimensionally.

5.4 Dynamic Road Test

5.4.1 Motivation

As described in Appendix C, the motivation for these dynamic tests would be to establish whether the dynamic results are accurate at the typical speeds required for our application. The requirement for the dynamic application is that the receiver's position update rate, extrapolation technique (required for the synchronization), calculation speeds, receiver filtering algorithms etc., are an adequate configuration for the dynamic application. Another factor which comes into play in the differential solution, is that the correction update rates and correction extrapolations adequately take into account the correction data characteristics (rate of change of correction rates - See [40]). The latter effects both the static and dynamic solutions but had thus far proven suitable for the static case.

The aim of the road dynamic tests (right next to the reference station), were to ensure terrain independence both in the ease of mobility, and in the direct Line of Sight (LOS) of the reference station. The program for this test, logged the dynamic data and displayed it whilst the test was running. The post processing software re-plotted the route taken whilst passing the way-points with the stake attached to the right hand side and is shown in Figure 5.15. The circled positions represent the way-points logged at the surveyed points. P6 was removed from the data set because it was incorrectly logged during the test.

5.4.2 Results

The results of the road dynamic tests are provided in Figure 5.16 and represent the terrain independent results in a 'friendly' environment. That is to say that these results purely represent GPS errors and those of the measuring technique employed. Compensation for measuring technique errors is depicted in Appendix D.

The dynamic accuracies would have been expected to compare with the results of the static test. The poorer accuracy of the 2 dimensional *static result* at the road site compared to that of the static tests, can be attributed to one of two effects. Firstly, the error could be due to the fact that the surveyed positions were used as the means in the standard deviation calculations instead of the mean of many loggings at one static position. This was however, meant to be accounted for in the compensation for the measurement technique error as random a effect with a zero mean (See Appendix D). The other account for these spurious results (the relatively good 3 dimensional result) could be due to the small data sets used to

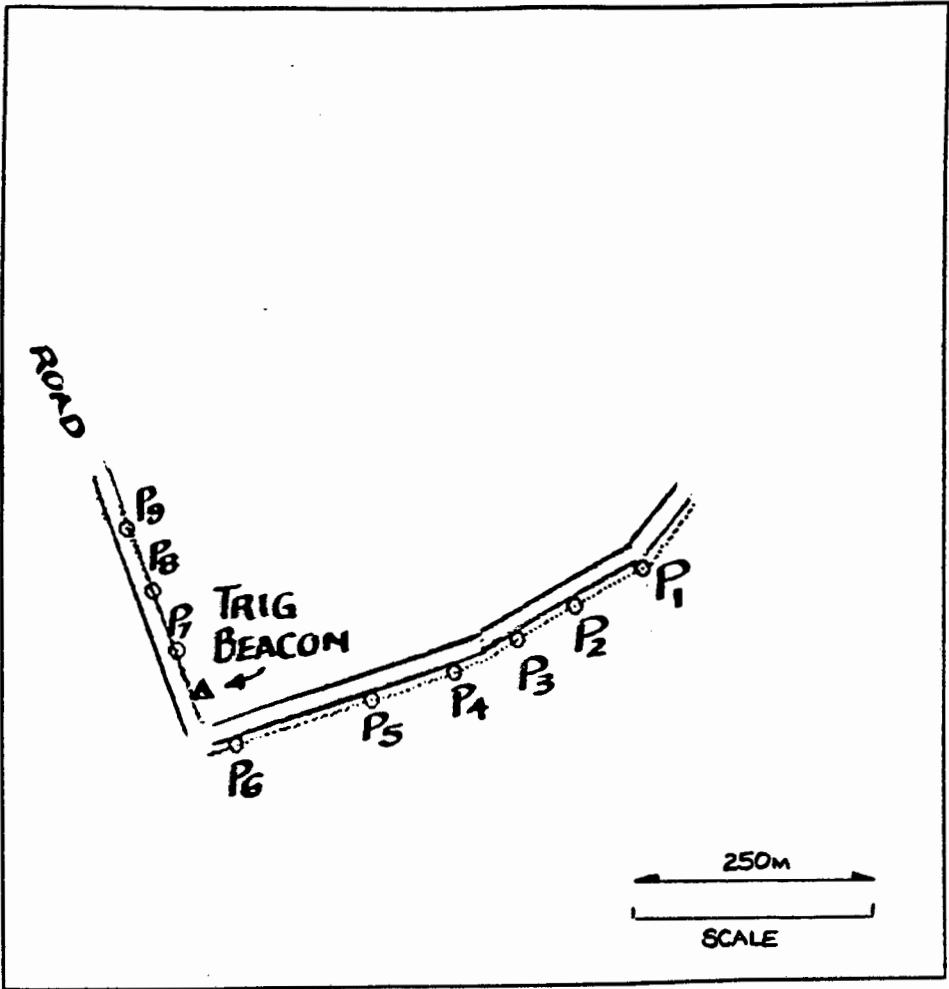


Figure 5.15: Plot of the logged way-points during the dynamic road tests (stake attached to the RHS of the vehicle)

ROAD DYNAMIC TEST RESULTS			
sigma (metres)			
Static 2D	Static 3D	Dynamic 2D	Dynamic 3D
3.089	3.418	9.588	9.64
		corrected	corrected
		7.078	7.13

Figure 5.16: Results of the terrain independent road dynamic tests

represent these tests.

Consistent with theory however is the fact that the 3 dimensional σ is worse than those of the 2 dimensional σ for both the static and dynamic cases.

Subtracting the constant calculated error offset according to the measurement technique employed, leaves an estimate of the dGPS errors in calculating a *dynamic solution* of the position. The results show that the dynamic case causes a substantial degradation of the positioning error. For a more detailed conclusion see chapter 7.

5.5 Dynamic Field Tests

The motivation for this test was the same as that for the road dynamic test except that it was desired that the spurious errors due to traversing the typical topography of a field at typical speeds be assessed. In addition, as will be discussed in Section 6.1, the terrain dependency effects of a typical field were to be established (i.e. loss of satellite lock, MP and loss of DTL).

The results of the post processing to plot the logged way-points of these tests are indicated in Figure 5.17 and Figure 5.18. The first figure is the plot of tagged positions taken statically at each way-point and the second is the plot of tagged positions in passing the way-points dynamically on the LHS of each flag. In the dynamic test, some points were missed due to the inability of approaching them at speed or because they were positioned on a field contour. Two points were mistakenly logged twice and two left out. The mis-logged points were not included in the processing that followed. In addition, the point ringed in red was left out as it was incorrectly surveyed on the grid. The strange pattern of vehicle movement was due to the existence of physical contours in the field which were difficult to cross except at the edges near the fence.

The compensations and error considerations for this test are the same as those for the road dynamic test. The calculation of σ in the dynamic field test however only used results with the measuring stake attached to the RHS of the vehicle. This is because the route about the field was such that on some runs to way-points, you were travelling east and on others runs to other points, west. This has the same effect as approaching a way-point from different directions. Another point is that to obtain absolute height information required that an adjustment be made to the height data obtained in this test. As previously explained, the reference information was incorrectly entered in the case of the reference station set up at the homestead. As can be seen by the static results, the relative results of the various σ calculations were not affected by this error.

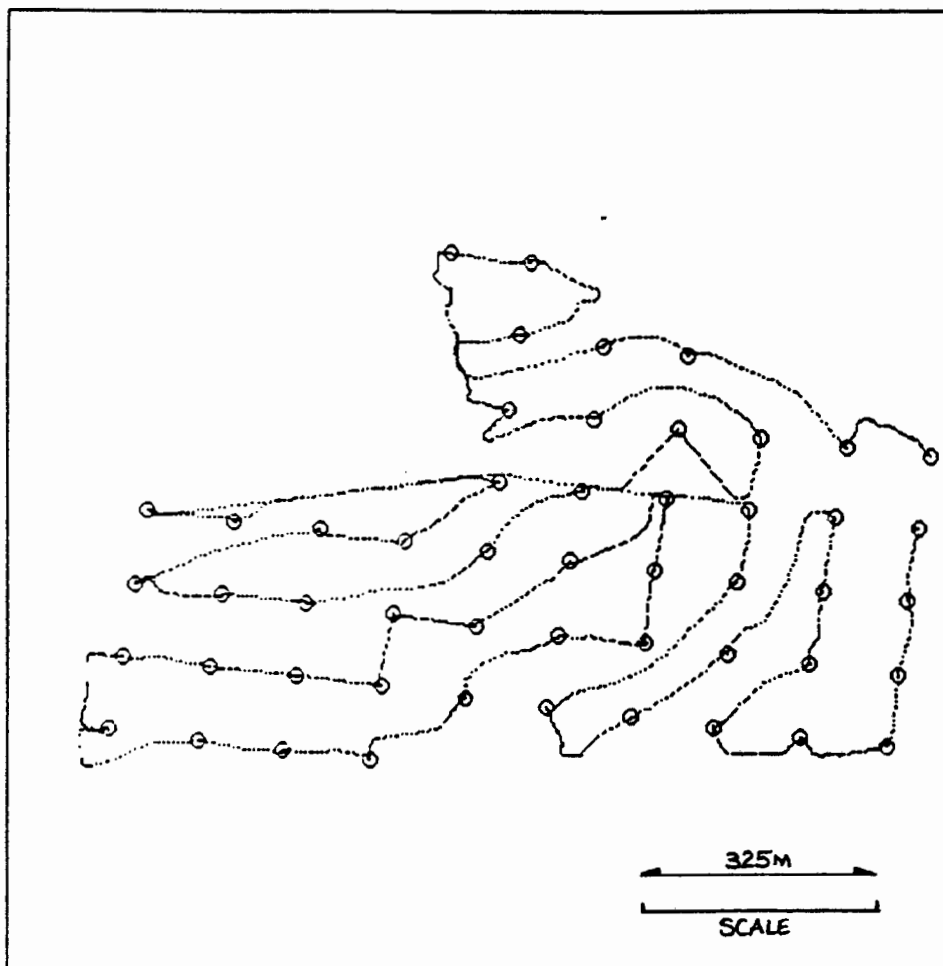


Figure 5.17: Plot of the logged way-points during the dynamic field tests (way-points were logged statically)

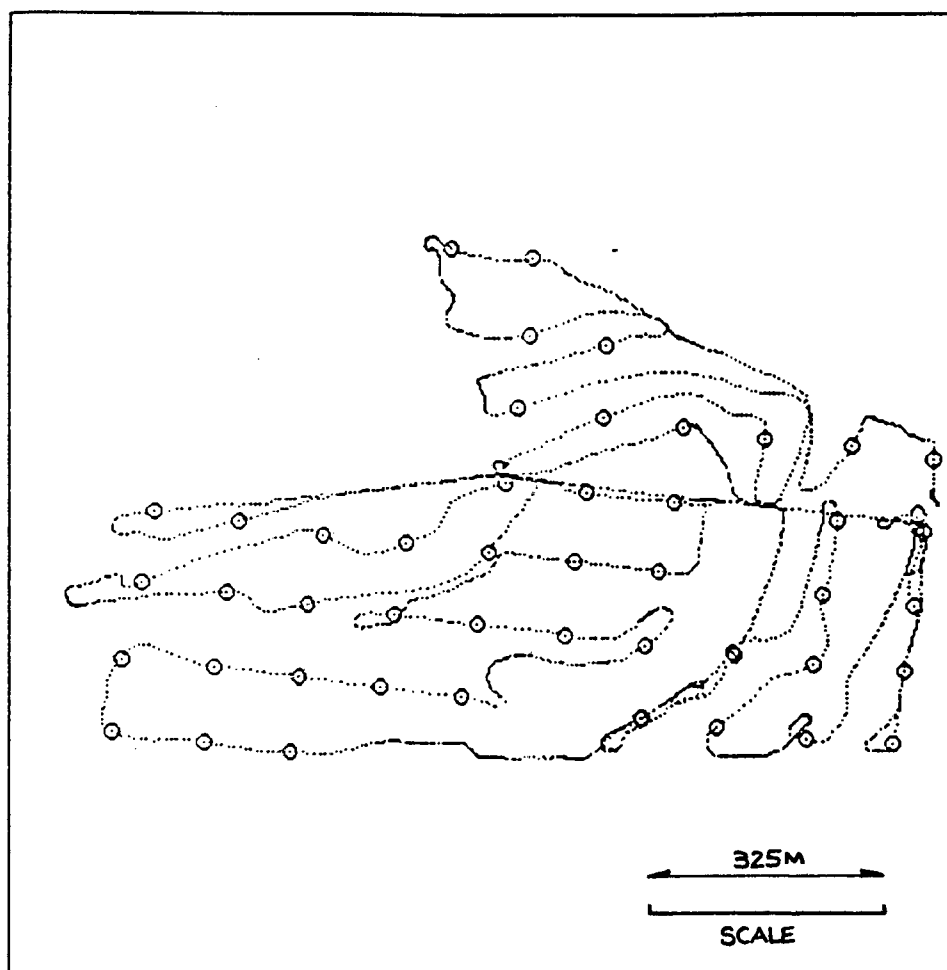


Figure 5.18: Plot of the logged way-points during the dynamic field tests (stake attached to the RHS of the vehicle)

The results of the field dynamic test are indicated in Figure 5.19. Again the surprisingly good *absolute static results* relative to those of the static tests, has to be attributed to the small representative data sets involved. The degradation in results resulting from the 3 dimensional solution as opposed to a 2 dimensional solution is evident. Subtracting the constant estimate of the measurement technique's associated error provides an indication of the degree to which the *dynamic solution* has been downgraded. In the case of the field dynamic test, the corrected results should indicate the performance of the GPS and any spurious terrain effects or mobility constraints. The conclusion that one has to reach, in the light of the inconsistent static results, is that you cannot conclusively attribute terrain or mobility effects to these results. These corrected results therefore also represent dGPS errors in dynamic position calculation. This is even more the truth considering the good static results obtained in the field relative to the poorer dynamic results.

FIELD DYNAMIC TEST RESULTS			
sigma (metres)			
Static 2D	Static 3D	Dynamic 2D	Dynamic 3D
1.416	2.569	7.455	8.031
		corrected	corrected
		4.945	5.521

Figure 5.19: Results of the field dynamic tests

The altogether better results of the dynamic field test compared to that of the road dynamic test were surprising. They couldn't be attributed to a better constellation configuration, as the PDOPs and number of satellites visible were comparable if not better during the road tests. Nor could greater surveying errors on the road be accounted for. In addition, the logged data indicates that the speeds during the road tests were not that much greater than those during the field tests. So although the degraded dynamic solution is due to the inability of the receivers to compensate adequately for the dynamic case, the level of that degradation is a complex function of receiver effects similar to those described previously in the 'Road Dynamic Test' section (i.e. correction data processing algorithms, dynamic position calculation or extrapolation algorithms and the spurious effects of ionosphere compensation, SA etc.).

5.6 The Implementation of the Sampling Phase Using dGPS

The purpose of this test was to determine the adequacy of dGPS in providing the spatial information for the samples that will be taken in the sampling phase. The various means by which the sampled data can be represented to make it useful for analytical purposes also needs to be established. Through an appreciation of the characteristics of the quantities of measure, it was hoped that the constraints of the spatially variable fertilizer applicator project could be better qualified. Specifically, some qualification of the required sampling density and accuracy of the positioning technique was needed.

5.6.1 Results

The samples were taken on an approximate 30m grid in the 'test field' and their locality is represented in the GIS representation of the digitized field of Figure 5.20. The point coverage plot overlaying the field was obtained from the averages of the logged positioning data for each sample (transformed to the digitized co-ordinate system).

A plot of logged GPS positions generated by the post processing software in Figure 5.21 indicates the spread of the positioning information within the sampling grid. Figure 5.22 shows the worst case of a spread of sample positioning information (sample ringed in red in Figure 5.21). This latter point still only has a σ value of .86m after logging positioning data for approximately 2 min.

The samples for this test were taken at each site by boring for two samples (about 15cm on either side of the sample site) and to a depth of about 25cm. This resulted in a .7kg sample for each point which was then taken to the laboratory.

The results of the analyzed samples can be found in Appendix L. Note that these samples were taken after uniform fertilization. This is not a problem however, as it was not the intention to make fertilizer recommendations, but to obtain an idea of the relative SV nutrient levels. These diagrams are produced using the GIS package in which a point coverage is labelled with the results of the analyses whilst indicating the true spatial relationship of the data. The graphics features of a GIS package can provide this type of data representation on screen and the various layers of results can be invoked for comparative purposes (see the last diagram in Appendix L for a representation of such an application).

Even the degree of variation depicted in these results was surprising and it was

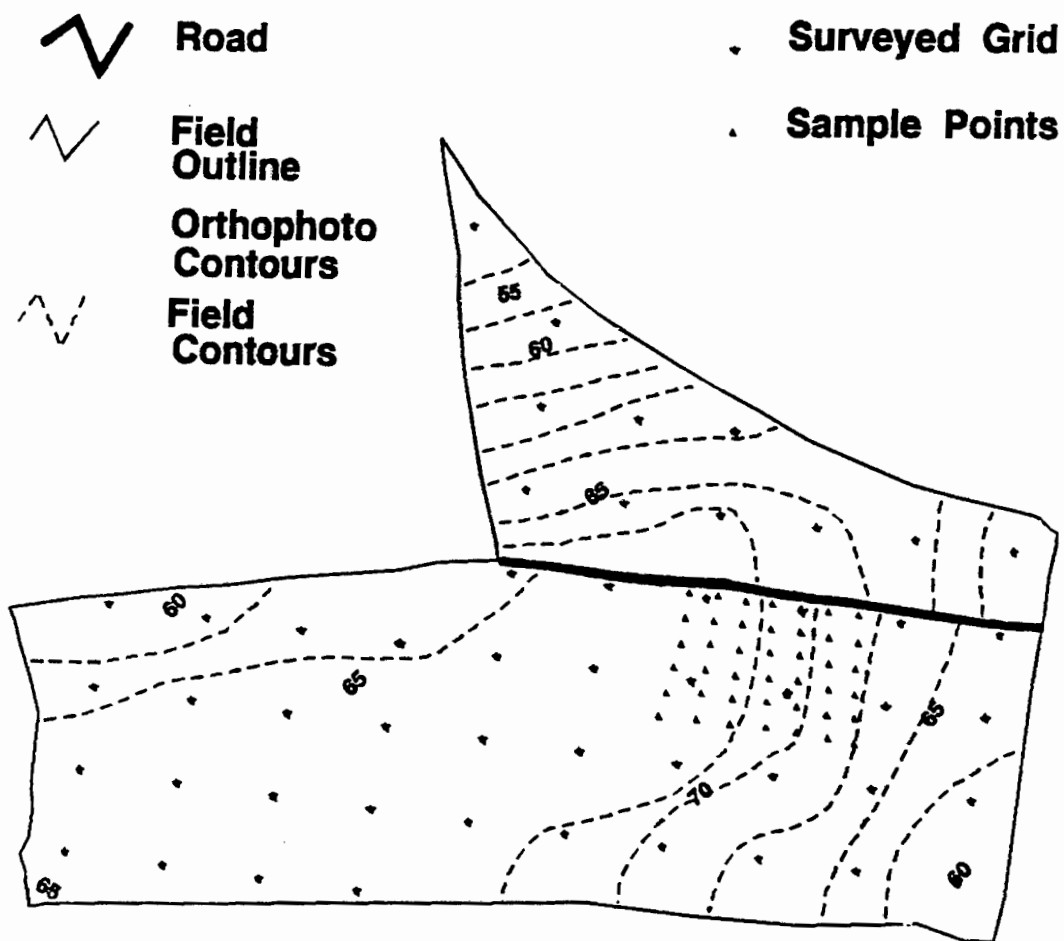


Figure 5.20: The locality of the samples in the test field

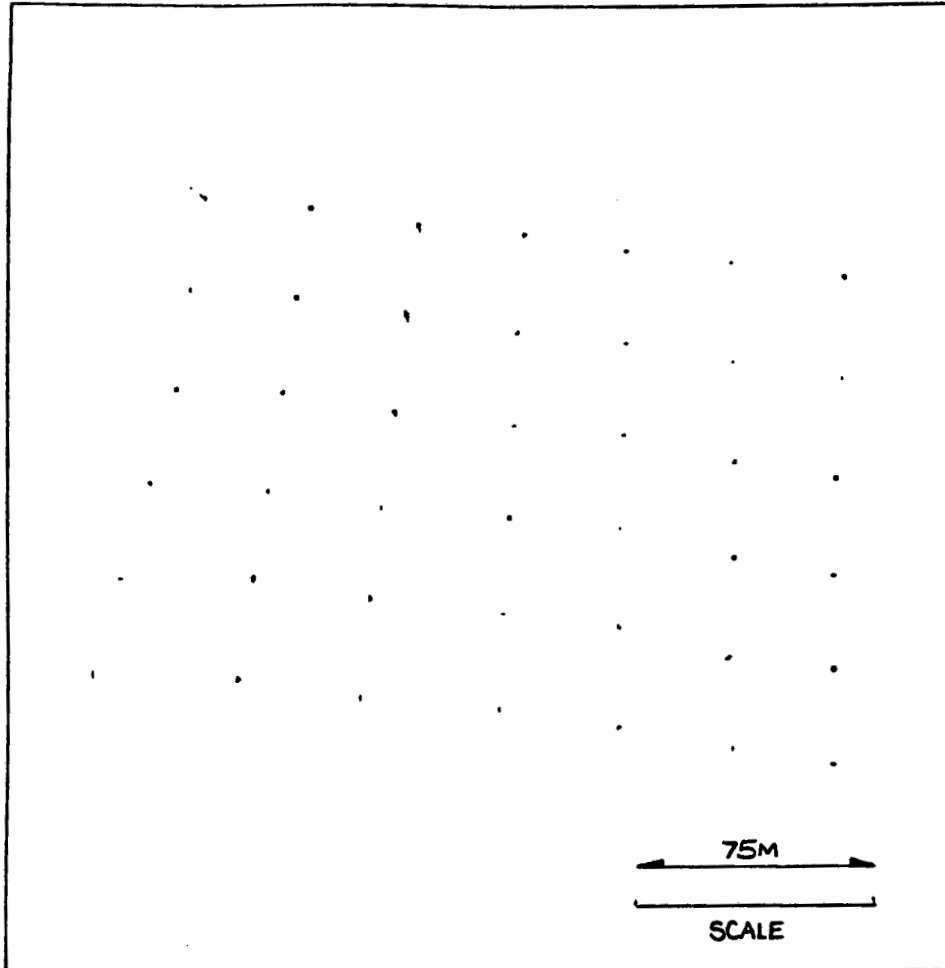


Figure 5.21: Plot of the logged positions at the sample sites

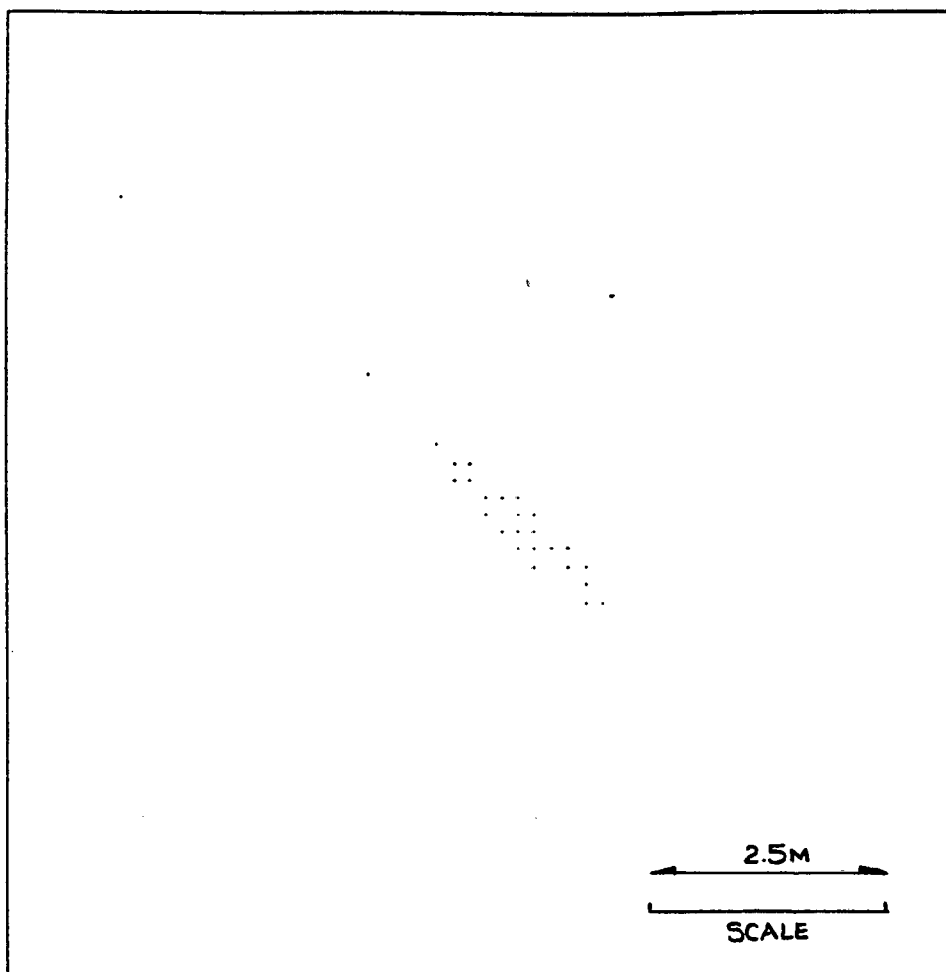


Figure 5.22: The spread of positioning data logged over a 2 min period at a sample site

hoped that leaf samples could be done at the same points to confirm the results. The reason for this redundant testing would have established whether the analysis from the soil sampling and those of the leaf sampling correlate. There is a lot of faith in the analytical methods employed, but the credibility of the soil sampling techniques need to be established. It was however, decided that the practicality (the test equipment is large and a vehicle could not be driven over the planted field) and time constraints were not conducive for these tests. It is recommended though, that these tests be carried out in a planned and controlled environment to establish the credibility of the sampling technique.

5.6.2 Other Representations of the Data

For a more intuitive representation of the data in the form of two dimensional contour maps and three dimensional representations, see Appendix E.

Chapter 6

Analysis and Discussion of Field Test Findings

This chapter describes the post processing of the field test findings into more meaningful results. Geostatistical techniques are relied upon heavily in evaluating the results of soil sampling. Finally, the processed field test results are discussed and evaluated.

6.1 Differential Link (or DTL) and Terrain Dependency Tests

The UHF DTL appeared to work adequately in all areas of the farm that would require DTL connections. All that is required is that the antenna is placed strategically on the vehicle. The low power (9W) operation proved adequate and the 30W application of the system was never invoked.

As a check, however, it is recommended that the good possibility of using the differential corrections string at the mobile station be implemented as a fixed and real time indicative parameter of whether DTL corrections are being received. Failing that, MP and loss of DTL effects can be established by monitoring inappropriate acceleration or bearing changes. This would require some additional experimentation and software design with the vehicle's speed indication as input; adding dGPS errors to that of the full range of typical vehicle speeds (It is likely that loss of DTL effects will be greater the greater the vehicle speed: confirmed in Figure 5.8). The other option of calculating residuals is seen as a bit of an overkill solution at this point. It is very easy to detect DTL failure in the static

case by means of velocity levels, but this has no significance in our real time dynamic application of dGPS.

If access to the differential corrections was obtained, then it would still be required to do some of the parameter checks described above for the detection of MP. Based on the results of these tests however, it would appear as though MP would never be a problem in the fields themselves and it is debatable as to whether MP was in fact at all responsible for any of the 'jitters' seen in Figure 5.2. MP problems are unlikely in this environment because of the roughness of the terrain, scattering the signals in every other direction. The area does not provide the mirror-like surface of the sea and is therefore not likely to produce MP effects.

Loss of satellite lock can easily be detected by observing the number of satellites in view (the 's' parameter for example from the GPS receiver). Loss of lock did occur in our typical test field, but would effect approximately 0.5% of the position data obtained for the entire field. The remaining fields of the farm appeared to have similar or better conditions and it would be fair to estimate that 98% of the cultivated land in this farm would be unaffected by loss of satellite lock terrain limitations. Loss of lock did occur in other areas off the fields and graphical plots of these effects were obtained.

6.2 Receiver Tests

The findings of the receiver tests indicated good receiver performance in tracking satellites down to the horizon and in providing extra functionality (such as mask angles etc.). In addition to these observations, extensive testing was done to establish that no smoothing algorithms had been implemented to disguise poor positioning accuracies and that the position update rate was adequate.

6.3 Static 'Mobile Station' Test

The inability to attest to *one* parameter predominantly or linearly determining the accuracy of the position determination leads to the conclusion that an estimate of the accuracy of a position calculation is a complex function of possibly 2 major parameters and a few other 'nuisance variables'. The determination of such a weighted function of these two variables is beyond the scope of this project. The results of the static tests indicate a dependence of accuracy on low PDOPs and a sufficient number of satellites, but the lack of linearity attests to the above arguments. What is important for the agricultural application however, is an

indication as to whether these accuracies are acceptable and reliable and an idea of the levels of these parameters at which the positioning accuracy will most probably be unsuitable.

The test revealed a 2 dimensional σ value of 2.22 metres with a PDOP below 2.692, 60% of the 24 hour period used to log the data. The significance of this value in terms of it's suitability for our application and therefore also the levels of acceptable PDOP values and number of satellites will be elaborated upon in the 'Accuracy Requirements' section following the results of the sampling tests (See Section 6.5.3).

A striking result is that 99.9% of the time, there were more than the 4 satellites required for 3 dimensional positioning and an over-all average of 6.03 satellites visible with the 8 channel receiver. There appear to be no problems with the constellation in its present form.

6.4 Dynamic Tests

To calculate a σ value for these tests, compensation for the testing procedure, an estimation of the errors involved and a strategy for the σ calculation had to be established. In this case, quite a few factors needed to be taken into consideration and these are depicted in Appendix D.

After a discussion of a few of the anomalies in these results, it was concluded that the dynamic application causes a substantial degradation of the positioning accuracy.

Three dimensional accuracies were worse than two dimensional accuracies as GPS has more difficulty in height determination.

In addition, in light of the inconsistent static accuracies in the field, you cannot conclusively attribute terrain or mobility effects to these results. These corrected results therefore represent dGPS errors in dynamic position calculation as around 4.9m.

6.5 Soil Sampling Tests

6.5.1 The Nature of Chemical Variation in the Soil

The implementation of an interpolation technique upon the sampled data, would not only assist in making the fertilizer recommendations more accurate and detailed, but could also provide additional insight into the nature of the variation. The possibility of implementing an interpolation technique could also have an effect upon the project implementation (such as the sampling density required when intense sampling is called for).

Soil properties generally vary with distance in such a way that the property at any point will be dependent upon the property at another point in close proximity. A very good linear unbiased estimator geostatistical (as opposed to classical statistical) technique, known as Kriging ([22]) can be implemented. Using the technique, the interpolation can be done and inference of valuable information relating to the properties of a particular chemical in the soil can be established. As will be explained later in this report, the latter benefits of this technique not only has agronomic significance but also provides insight into the required sampling densities and positioning accuracies required for the fertilizer application project. In fact having quantitative data as to how a particular property varies in the soil, could effect the entire perspective of the project as these are the very quantities the project is aimed at correcting.

A more detailed explanation of the Kriging and Cokriging techniques is available in [22]. The formulae and a brief explanation of the results will be given in this report.

The first step towards implementing the Kriging interpolation, would be to plot the semivariance function or the semivariogram. This plot provides invaluable information relating to the nature of variation of a chemical in the soil and also provides insight into the degree of variation.

The mathematical description of the semivariogram function is given in Appendix F.

Figures 6.1 to 6.4 present the plots of the semivariograms of various chemicals calculated by means of a post processing program given in Appendix G.2. The plot of the semivariance values for %C, for example shows a definite increasing characteristic (possibly exponential) with distance. As is expected with most semivariogram plots, there is a certain range at which the characteristic becomes random. This distance correlates to the distance at which the data obtained is no longer spatially dependent and characterizes the nature of variation for

that particular chemical by defining a quantity known as the range of spatial dependency. The results for K and P also show an increasing characteristic with distance. The results for the pH however, indicate a random effect over the whole range and if there is a spatial dependency for pH results, then the sampling density for these tests is not adequate for its inference. It is clear therefore that pH results are more spatially variable than other chemicals plotted.

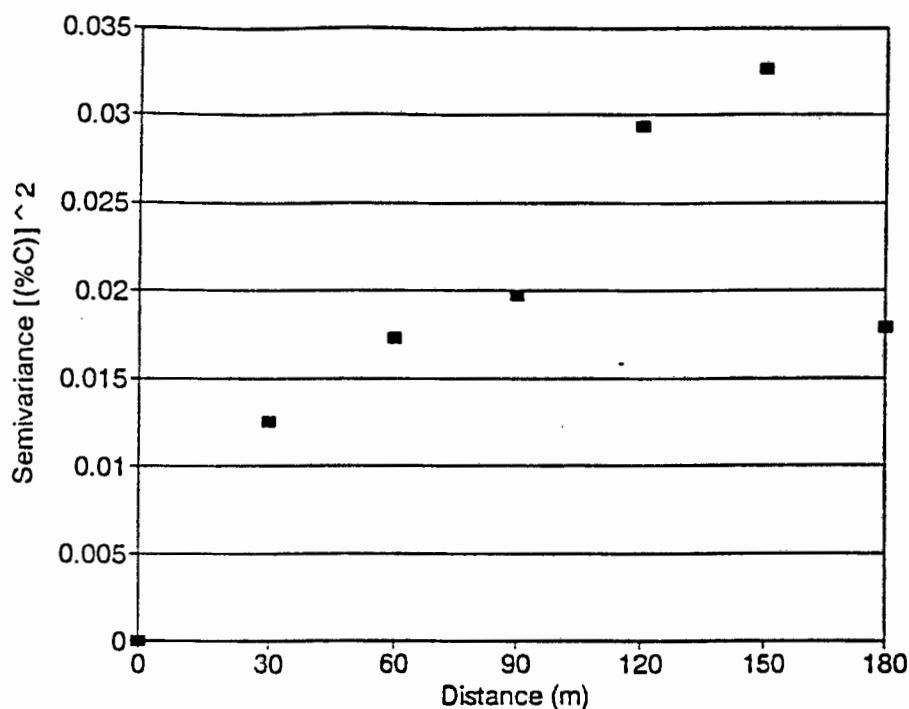


Figure 6.1: Semivariogram of C using all the data taken at the 42 sample sites.

The underlying functions for the semivariogram results obtained for P and K, are not immediately obvious. This can be explained by an overview of the raw data obtained for P and pH for example, which show areas in which some abnormal results were obtained in certain areas. These areas are indicated in Figure 6.5 in which those samples are ringed and plotted together with the approximate 'field' contours for comparative purposes. This is again a GIS output.

The strange results obtained next to the road can be attributed to the fact that chemicals could have been dumped there for distribution. The strange results in other areas could be due to a sample being taken at a site in which there was an overlapping application of chemicals (and the contoured fields certainly do not ease the likelihood of these occurrences considering the application patterns). Other possible explanations could be due to poor sampling techniques or in the event that a granule of undissolved chemical found its way into a sample. The

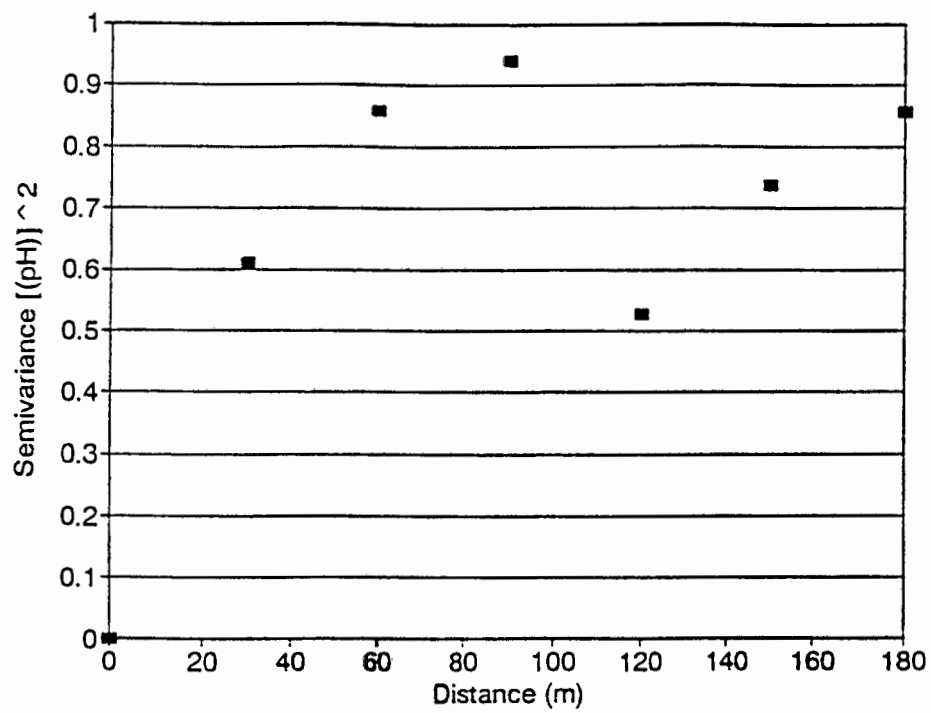


Figure 6.2: Semivariogram of pH using all the data taken at the 42 sample sites.

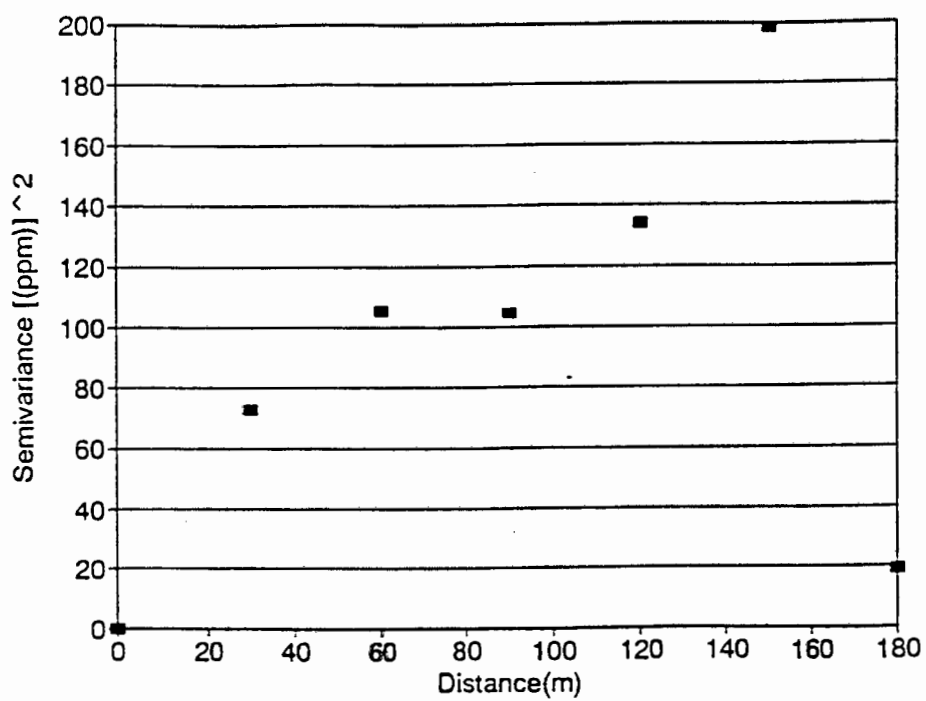


Figure 6.3: Semivariogram of P using all the data taken at the 42 sample sites.

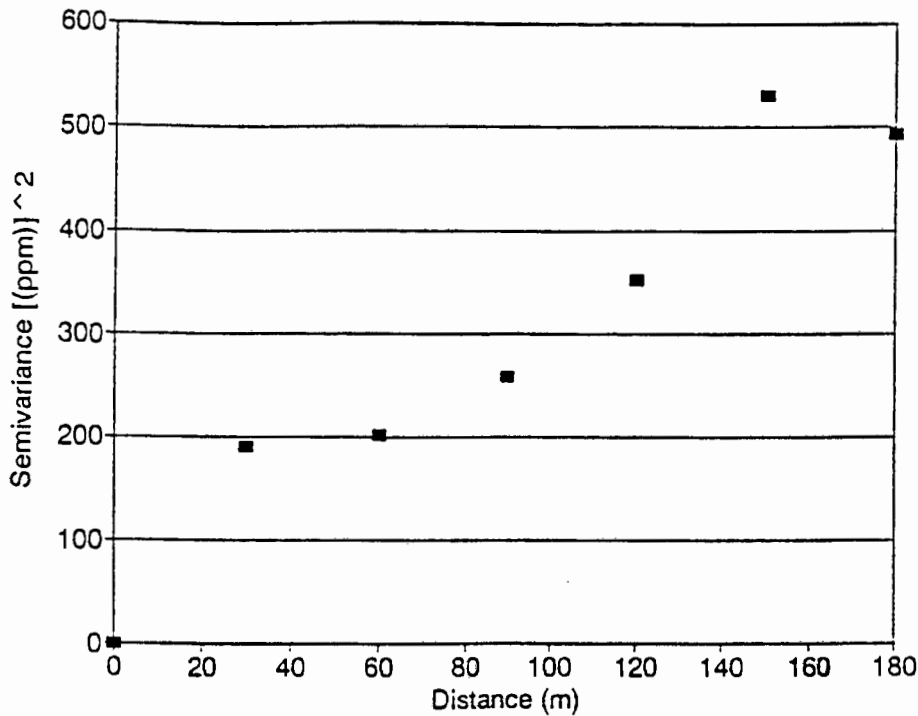


Figure 6.4: Semivariogram of K using all the data taken at the 42 sample sites.

latter is unlikely as liquid fertilizers have been applied to this field for a number of years. Other than by these effects, the other areas in which strange variation occurred cannot even be explained due to an alignment with the contours (therefore not receiving or using the chemicals in the soil or perhaps having been a dump site for chemical distribution). The conclusion is that apart from the road, the other results can most probably simply be taken to be due to the variation which can occur in the soil. If it was decided that the variation in samples were due to spurious effects of sampling techniques or application misses or skips, then the sampled data could be filtered in such a way as to remove radically different observations from the data set. This would be a dangerous procedure however considering that it is the variation that is wished to be measured; exactly the information that an incorrect tolerance level on such a filter could obliterate. One more point to note is that despite the strange bands of values observed in these tests, the semivariograms still indicated a definite spatial dependence.

If the 7 samples next to the road are eliminated from the data set, the characteristics for P and K becomes more visible. A best fit curve can be fitted through the semivariance data according to various models. The two used for the K and P respectively in Figure 6.6 and 6.7 were a linear and exponential model. Again, the mathematical descriptions of these models are given in Appendix F.

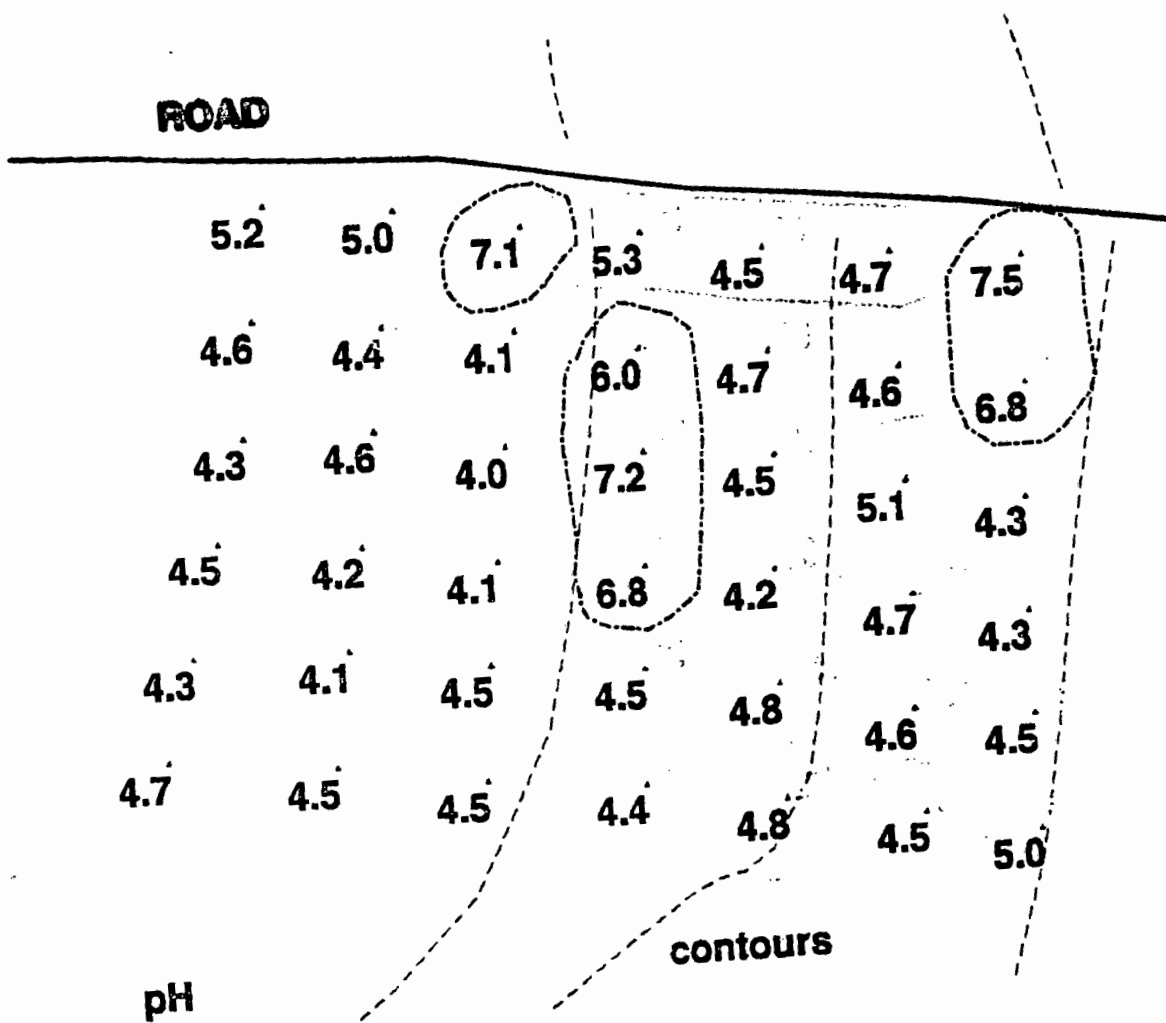


Figure 6.5: Abnormal sample results

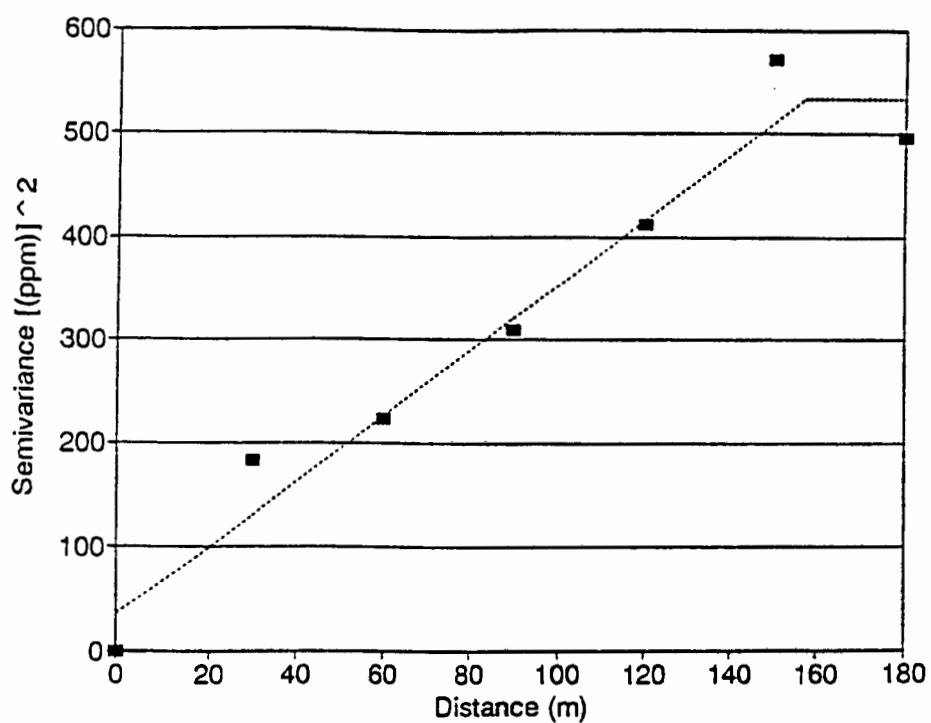


Figure 6.6: Semivariogram of K using only the data taken at 35 sample sites.

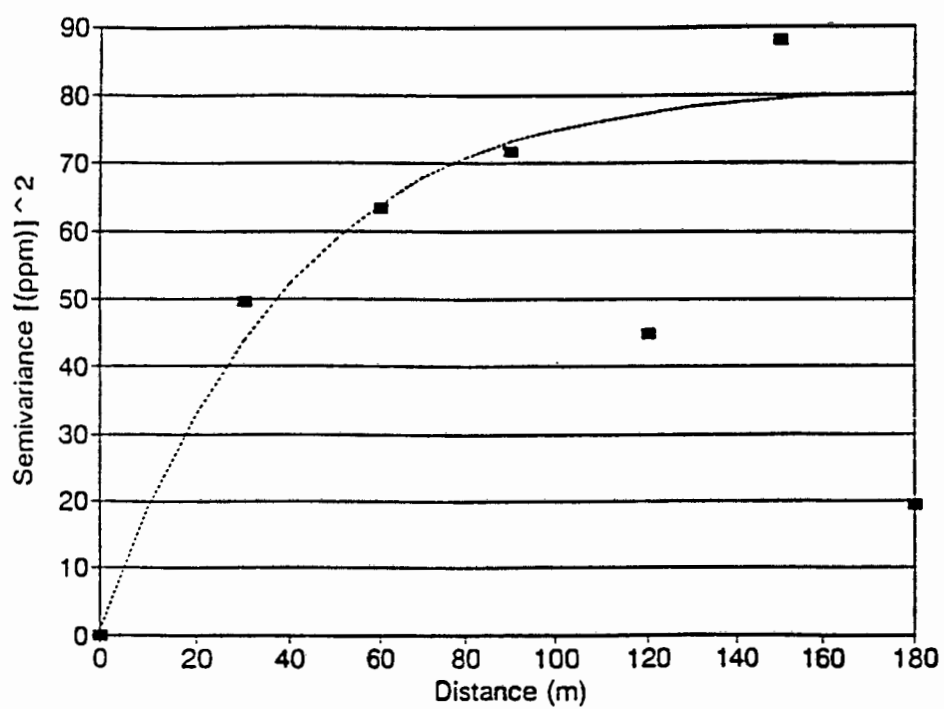


Figure 6.7: Semivariogram of P using only the data taken at 35 sample sites.

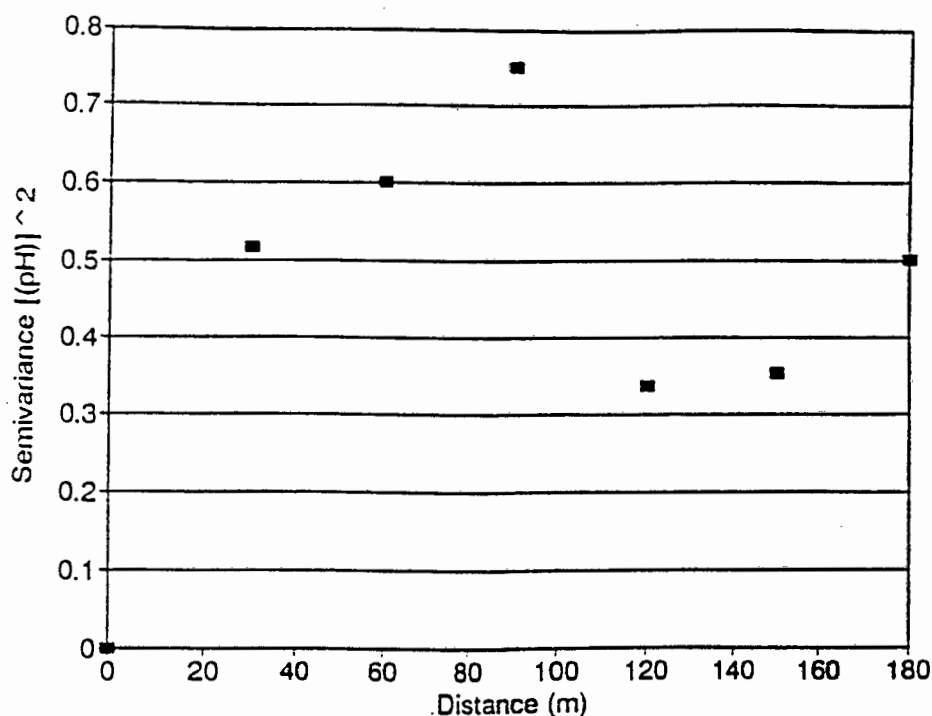


Figure 6.8: Semivariogram of pH using only the data taken at 35 sample sites.

For K, the least squares solution (of the first 5 points of the semivariance function) produced linear parameters of $B = 3.168$ and $C_0 = 35.5014$. C_1 was estimated at 533.3 and 'a' at 157.078m. The theory indicates that when the nugget (C_0) was not zero it indicated that there was a sampling error due to measurement error or that the sampling distance is too large to detect spatial correlation at small separation distances. It appears as though the former could be the case in this instance.

Because of the non-linearity and the number of unknowns in the exponential model, the parameters C_0 and C_1 were first estimated and a_0 calculated accordingly through the linearization of the above equation and the method of least squares. The Gauss Newton method, uses this initial estimate of the parameters to establish a set of over-determined linear equations. The solution of these equations using the matrix solution of the method of least squares, produces a better estimate of the parameters. The final model used had $a_0 = 38.9201$, $C_0 = .6026$ and $C_1 = 80.6152$. Only the first 4 points produced by the semivariance function were used to represent the model.

As can be seen in Figures 6.6 to 6.8, the results using the reduced data set, created much the same pH random plot. This confirms earlier observations. As suggested by this data and according to the work done on pH values in [42], a

sampling density of 15m is proposed if the nature of the pH variation is to be determined and interpolated. Whether the applicator will be able to compensate for the pH with such detailed information is another matter to consider.

So the semivariogram provides a great deal of useful information. Firstly, the vertical axis can give an indication of the variability of that particular chemical in the soil. This indication of variability can help with management decisions as to whether intensive sampling is required or not, or if a more generalized policy of SV application should be implemented. The range of each chemical, is a fingerprint of that particular chemical (although it could be different in a different type of soil and requires further research). This range can be used to infer the sampling density required for the determination of the semivariograms and interpolations. Specifically in the case of the exponential model, sampling density must be smaller than the exponential 'time' constant to ensure that the shape of the semivariogram is accurately determined. From these results, a sampling density of 30m or 35m is sufficient for K data and of less than 38m for P.

An explanation of how this semivariogram data can be used to determine the accuracy required of the positioning technique is described in the next section.

6.5.2 Interpolating Data

The use for which this semivariogram was actually produced is for the interpolation of the data. The Kriging technique accomplishes this by weighting the information of the surrounding sample points with use of the information obtained in the semivariance diagram.

The Kriging equations are described in Appendix F.

A program (Appendix G.2) was developed to implement this technique and determine the interpolated values. The solution of the set of linear equations that resulted were solved using some 'numerical recipes' or functions in 'C' which decompose the matrix into its LU equivalent. The effectiveness of the technique in adding detail to the sampled values is evident in the contour maps. As the first row of samples next to the road were omitted from the data set, the remaining 35 samples were used to implement the Kriging algorithm. The results for P and K are shown in Figures 6.9 to 6.12 displaying both the contours for each and the associated 3 dimensional pictures. These are all GIS and statistical outputs using the interpolated data from the program instead of the sampled data of the actual test.

It is also worth mentioning that a measure of the goodness of the interpolated value can be obtained using the Kriging technique. This value is the minimum

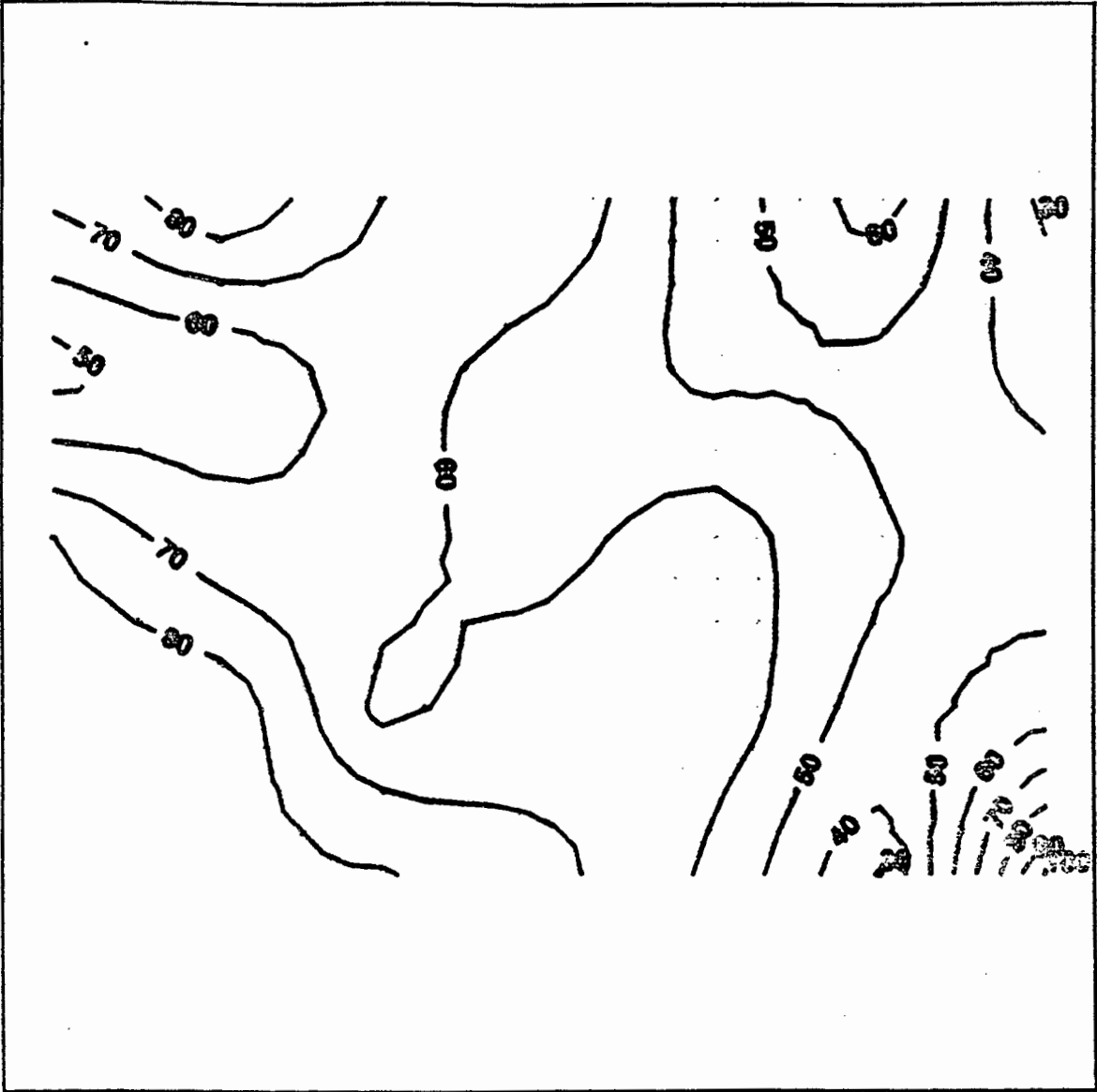


Figure 6.9: The contours of the interpolated data using the values of K for 35 samples

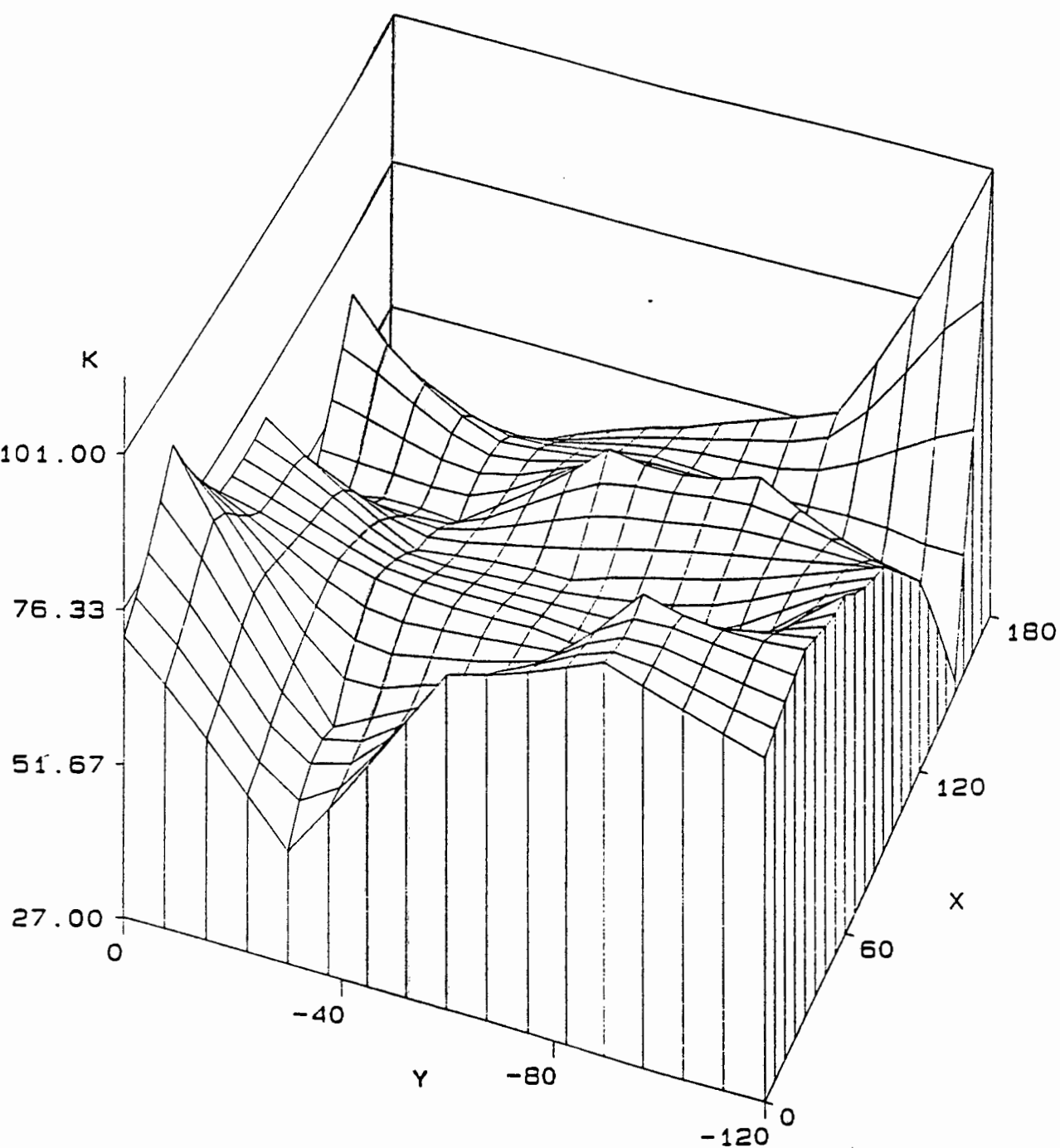


Figure 6.10: The 3 dimensional representation of the interpolated data using the K values of 35 samples

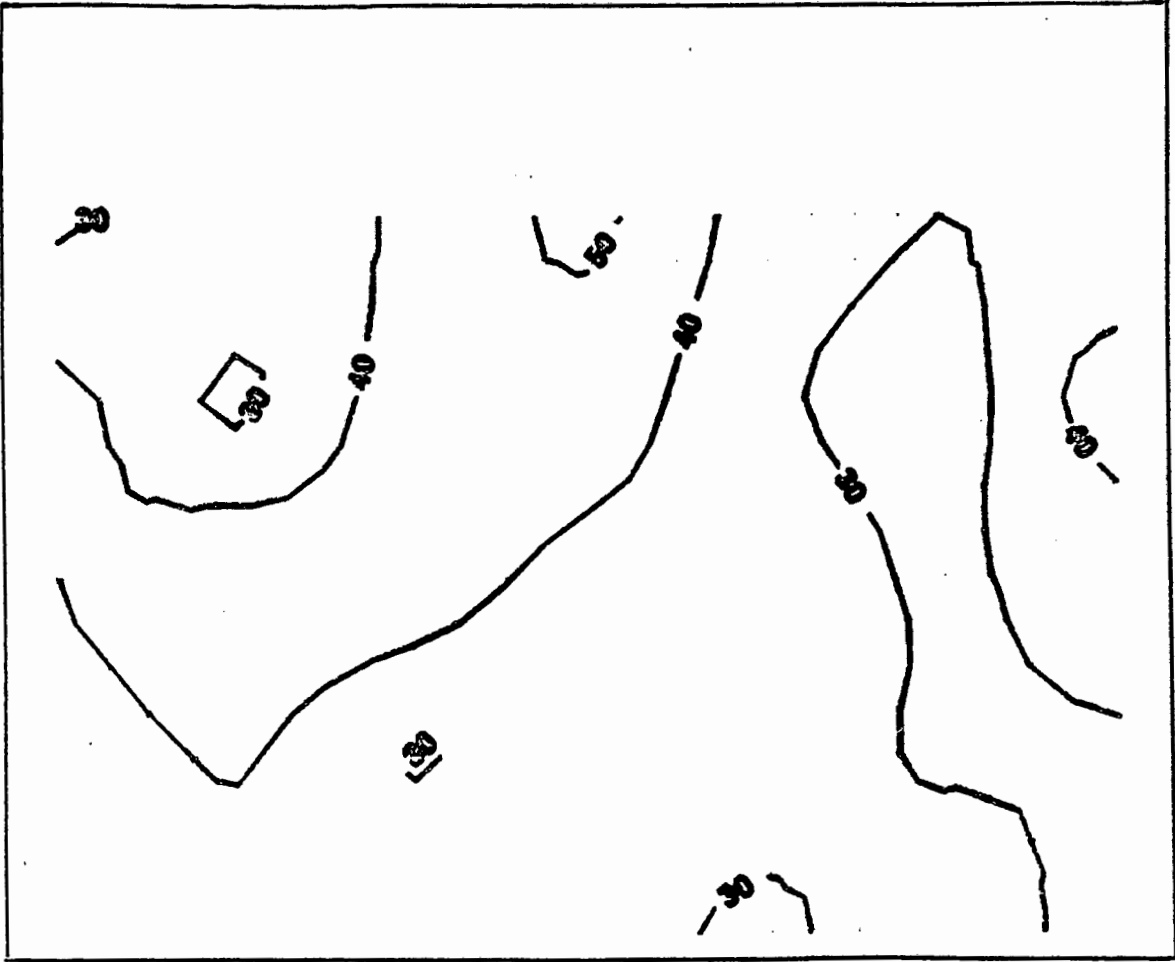


Figure 6.11: The contours of the interpolated data using the values of P for 35 samples

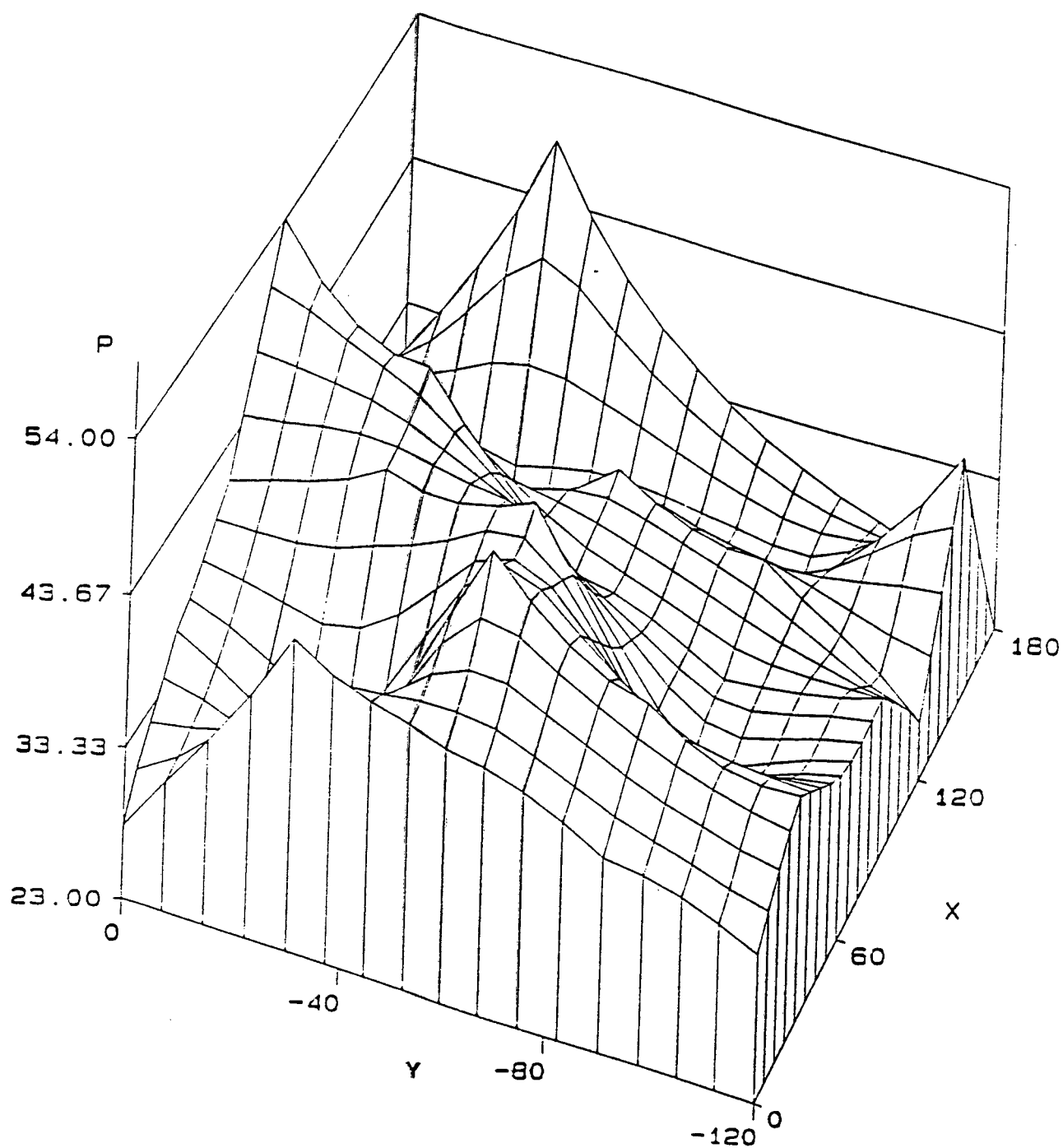


Figure 6.12: The 3 dimensional representation of the interpolated data using the P values of 35 samples

estimation variance or $\sigma^2(x_0)$ (See [22]). This value may have significance in assessing the suitability of an interpolated value for making fertilizer recommendations.

The method of Cokriging is also explained in the same paper. The significance of this technique is that it can be used to determine a property of the soil that is difficult to measure or to map a property that has had some of its sampled data discarded due to bad laboratory practice etc. The prerequisite of this technique is that the property concerned has a spatial pattern that is spatially correlated to the spatial pattern of another property. That is to say that the two properties are spatially correlated. The technique requires the determination of a cross-semivariogram.

6.5.3 Accuracy Requirements Determined by Soil Variability

The accuracy requirements of the positioning technique are not really determined by the sampling phase or the harvesting phase. In the former case you can log data for a fair period of time at a static point improving the accuracy of that point's position the longer you log the data for. As for harvesting, you can post process the data to a certain extent or filter it into straighter lines. An approximation of the accuracy with which the driver can navigate whilst harvesting can also be used to improve these position estimations. Even if it isn't assumed that the driver drives such that consecutive paths do not overlap by a certain tolerance level, harvesting information can be filtered and a reasonable requirement on positioning accuracy would then be that the position calculations spend 50% of its time within the harvester's boom-width and 50% of its time in either of the neighbouring lanes. This would be equivalent to a standard deviation of 3.67m with a harvesting boom-width of 5m. This is very conservative however and it can be assumed that the harvesting accuracy requirement will not be the limiting factor because of its non real time implementation.

As has been mentioned, some application grids are as large as 2.5 acres and still produce substantial results (in fields showing large enough variation). If more precise applications are required, things can only improve. The actual size of the applicator boom-width puts an upper limit on the degree to which fertilizer can be applied spatially variably (assuming still uniform application across the entire boom-width). The real time requirement of this phase of the project, defines the accuracy requirement of the positioning system for this project. Ultimately, it is the variability of the chemicals in the soil which we are trying to correct and they determine the positioning accuracy requirement of the applicator. The worst case would be if chemical concentrations were to undergo step changes with distance.

The result of this would be that if the position determination were out by even a small amount, it could not be guaranteed that the correct amount of fertilizer was being applied at any point. Luckily this is not the case as the chemicals of interest, such as potassium and phosphorous, have a spatial dependence upon chemical concentrations at other points (as indicated by the semivariograms of the last section).

To illustrate how the semivariogram can be used to estimate the positioning accuracy requirements, the following example is given. Based upon some fertilizer recommendations, it appears as though an approximate change of 25% in chemical concentrations results in a change of say 25 kg/ha of a particular recommended fertilizer product. In the case of phosphorous, a 25% change from the mean of all the samples taken (39.14 ppm) is approximately 10 ppm. Looking at the semivariance diagram obtained for phosphorous, a typical distance at which such a variation could occur would be larger than the range of the semivariance function (of about 90m). This is in *this* case, in which the variation of phosphorous is not that substantial. Now for potassium, a 25% change from the mean of (60.6 ppm) is 15ppm and that relates to 60m in the semivariogram. The idea of these calculations is that it provides an indication of the accuracy requirement of the positioning technique for this particular application in this field. Now it can be said that the accuracy of the positioning technique such that the applicator will not be applying the incorrect amount of fertilizer at a point would be that it not be out by more than 60m. On this field then it is not at all likely that the positioning technique will fail the application. Note that these results would not hold for every point in the field, but are aimed at providing an educated guess as to the positioning accuracy required.

If however, the variation of a chemical produced a 25% change in say 10m (very likely with varying pH values for example, with its short semivariance range), then the accuracy requirement of the positioning technique would be more critical. The required σ value could be determined from the amount of Rands one is prepared to lose due to inaccurate application (note: a heck of an improvement from conventional application techniques; but the requirement nonetheless short of perfection¹).

For example, say the recommendation for a 50ha field required an average of 525 kg/ha of fertilizer product and the farmer was only prepared for the possible mis-application of 62.5 kg over the whole area (Rands equivalent). A bad position representation causing the applicator to think itself in the next application grid management cell (10m grid in this example), will result in an incorrect change in

¹These results are dependent on the assumption of perfect applicator control, perfect data representations for the estimations of the fertilizer requirements and not taking into effect the effects of uniform application over the applicator boom-width.

application rate of 25 kg/ha. This can be converted to the equivalent amount of field that can be allowed to be misrepresented by:

$$\begin{aligned} \text{fieldpercentage} &= \frac{\text{wastekgs}(kg)}{\text{fieldsize}(ha) * \text{wasterate}(kg/ha)} \\ \text{or } \frac{62.5}{50 * 25} &= 5\% \end{aligned} \quad (6.1)$$

This calculation determines that only 5% of the position estimates can place you in the wrong management grid cell. By virtue of a normal distribution of position, a 5% chance of miscalculating position to 10m to result in a change of application rate, requires that $2\sigma = 10\text{m}$ or σ is 5m.

The results of the static tests indicated a σ of 2.22m. The chance of getting a position miscalculation of 10m is 0.00006%. On a 50 ha field that is equivalent to a misplacement of .075 kg of product. Alternatively, for the same allowable misplacement of 62.5 kg over the whole field, the upper limit on variability in the soil would be that it could change by 25% within 4.44m.

Failing these arguments, if the variability is not such as to cause concern with the positioning technique, the minimal requirement for the positioning technique accuracy would be the same as that for the harvesting phase (assuming it is desired to record the application rates vs position in the field). This argument maintains then a positioning accuracy requirement of $\sigma = 7.35\text{m}$ with an applicator boom-width of 15m.

6.6 The Limitations of the Positioning Technique in Light of Previous Discussion

The logging of relief data (3 dimensional positions) is a requirement in all cases where height does not remain constant but only the 2 dimensional accuracy of the 3 dimensional measurement is significant.

According to the *static* accuracy results, the PDOP results indicate no upper limit in the range of values obtained, that would relate to accuracies that are unsuitable for the soil variations obtained through the sampling exercise. In fact, the worst case PDOP still related to an accuracy which could cater for soil variabilities far in excess of those experienced in our tests. The harvesting phase however, indicates that a PDOP of around 4.2 should provide a warning as to

the possibility of inadequate positioning accuracy (i.e. if we were to stick to the stringent estimate of a σ requirement of 3.67m for this application).

As for the number of satellites, naturally the visibility of less than 4 satellites will be indicative of poor positioning accuracy (but only occurs .1% of the time). The results did show however, that the solutions obtained with four or more satellites provide adequate accuracies for all phases of the fertilizer applicator project requirements and for soil variabilities far in excess of those experienced in the sampling tests.

According to the arguments of Section 6.5.3, the results of the *dynamic* field tests, which indicate a more realistic estimation of the performance of the dGPS technique for our application, would allow for less soil variation than the results of the static tests. Based on the results of the sampling carried out on the field however, the 60m limit determined by the potassium variability, is way out of range for concern for the dynamic accuracy of the dGPS positioning technique.

For greater degrees of variability the dynamic accuracy could become inadequate. If for example, the stringent requirement that only 62.5kg can be misplaced over a 50ha field, the greatest variability that could be catered for according to the 2 dimensional dynamic field test results, would be that a chemical not vary by more than 25% in 11.042m. Even a K variation that is considered to be highly variable (such as the one depicted in [22]; 25% change over approx. 40m) would be competently catered for by these accuracies. The highly variable P case presented in the same paper has an even stricter requirement in that a 25% change can occur in about 10m. There would still only be about a 7 percent likelihood of a bad position calculation in this case and an incorrect amount of fertilizer being distributed (or a misplacement of 82.5kg over a 50ha field).

Now the maximum requirement of a 25% change in chemical concentrations over 11.042m could be limiting in the case of pH compensation (or chemicals with very short ranges of spatial dependence) or other highly variable chemicals. However, neither would pH compensation be possible with uniform application over the boom-width of the applicator. In fact, no matter how good the positioning technique, the limit on soil variability that can be catered for with uniform boom-width application is determined by the applicator boom-width itself ($\approx 15m$). According to this argument, the dGPS dynamic solution must be able to distinguish between 15m grid sizes with a reasonable accuracy. This is most adequately catered for by the dynamic accuracies achieved in these tests.

It is also necessary to note that the levels of dynamic accuracy calculated loosely (with this approximate measurement technique) in these tests, could be bordering on the edge of them being unsatisfactory for harvesting data acquisition. It may be difficult to correct the positioning information of the harvesting phase

and logged application data even in post processing with these or slightly worse accuracy specifications. A study of post processing techniques of dynamically logged positioning data (in consideration of the harvesting and application boom-widths) may be beneficial to determine if the positioning requirements of such a study provide less stringent limits on the accuracy requirements than those estimated in Section 6.5.3.

The effects of bad PDOP levels as indicated in the static tests, could be proportionally applied to the dynamic tests if more consistent dynamic results were obtained. For example, say 5.521m could be taken as the consistent dynamic σ value, and a distance of 15m represented the variance of a chemical at which a different amount of fertilizer would be recommended. Allowing say a 5% chance of an incorrect position calculation into another grid cell of recommended fertilizer rates (resulting in fertilizer misplacement) would result in a corresponding σ value of 7.5m. Assuming that a σ of 5.521m is proportional to the σ obtained in the static tests, then the degradation of σ to 7.5m would be due to a PDOP of 5.088 (assuming linearity at the mean of the results depicted in Figure 5.14). Such a PDOP could then be used as a warning in real time as to the possibility of an unacceptable position accuracy. Similar conclusions could be made with the 'number of satellites' results.

Chapter 7

Conclusions

In accordance with the user requirements and based upon the findings of this report, the following conclusions are proposed:

The *investigation* into the topic of site specific farming resulted in the identification of the tools and technology required for the SVFAP. The literature review also confirmed the feasibility of the project. More specifically, the following points are noted:

1. The agronomic aspects of this project were covered superficially during the project investigation due to the requirement that greater emphasis be placed on the engineering aspects of the work. The project does however require a great deal of agronomic support and input if it is to be successful. This point became apparent, and was explicitly pointed out a number of times in various literature. References to this literature are provided in this document and contain vital information. These documents should be passed on to the scientists involved.
2. GPS and GIS were established as technologies with particular relevance to this project. Differential GPS was the positioning technology considered most suitable for our requirements. Previous developments gave valuable references and ideas with regards to the selection of the optimal GPS solutions. Peripheral sensing equipment, crop yield meter options and the available software developments were discussed.
3. The soil sampling strategy was investigated and the combine harvester, sampling car and applicator vehicle operations studied. Based on the findings of this report, it is recommended that the existing sampling technique be assessed in terms of its accuracy (leaf sample correlation) and its practical suitability for intensive sampling.

4. Based on the literature review undertaken for the purposes of this project, the SVFAP implementation seems well justified. There seems to be wide interest in all areas of site specific farming throughout the world. The particular lack of site specific practices in this country has made it difficult for the timeous development of this project.

The *experimental testing* of the SVFAP design provided valuable insight into the practicality of the chosen solutions:

The experiments better qualified the SVFAP in terms of the procedures required to implement soil sampling. The hardware and software requirements for soil sampling, yield mapping and fertilizer application were also clarified through the practical constraints of the field tests.

For example, more insight into the sampling strategies (Section 3.1.1) and the correct positioning of a GPS reference station was gained. Various other practical limitations were also identified. The specific hardware requirements for a DTL and dGPS configuration were established and the problems and solutions relating to the powering of a remote reference station were encountered during these tests. Finally, the need for navigation and careful timing considerations in the software interfacing were some of the software insights gained through this research.

The following conclusions could be drawn from the *findings and analyses* of the field tests. These results have particular relevance to the suitability of dGPS as a positioning technique and the use of the SVFAP design philosophy for soil sampling.

1. The results indicate that there were very few limiting terrain dependent effects influencing our positioning accuracy in the agricultural environment. It was established that no multipath effects and very limited loss of DTL (if any) were encountered within the cultivated land. It was observed that a means to detect the occurrence of the loss of the DTL is necessary. This could be best achieved through access to the string of corrections from the GPS receiver or by inference from inappropriate velocity levels or bearing changes. It was also established that 'loss of satellite lock' terrain dependent effects were minimal over the extent of the cultivated land for these tests.
2. Valuable insight into the GPS technology was achieved through the field tests. A knowledge of what to look for in a receiver, what the specifications imply and the various GPS configurations was obtained. The Trimble receiver used in the tests maintained the specified positioning accuracies and quoted update rates and proved to be a highly reliable (and robust) receiver.

3. Static positioning tests revealed that the positioning technique is reliable in terms of its consistently good performance and the sound state of the constellation. It was established that the positioning accuracy is a complex function of PDOP values and the number of visible satellites as well as various other indeterminable effects. Static positioning accuracies for all combinations of PDOP and satellite visibility, catered adequately for soil sampling, taking the in-field soil nutrient variability into consideration. The worst PDOP recorded did relate to an accuracy which may not be adequate for data acquisition in the harvesting phase.

In general, the results of the static positioning and soil sampling tests indicate that the positioning technique's *static* accuracy is suitable for the sampling, harvesting and application phases. Calculations for the accuracy requirements of the application phase can be made by taking the soil nutrient variability and the user's tolerance on misplaced chemicals into account. In such an example it was shown that the static accuracy was adequate, providing the chemical being compensated for did not vary by more than 25% in 4.44m. This would result in the misplacement of 62.5kg of product over a 50ha field with an average application of 525kg/ha.

4. The accuracy of the dGPS dynamic positions are poorer than those of the static solutions. No evidence of spurious mobility or terrain effects were discovered in the test field. If a more accurate redundant position measurement technique were to be employed, perhaps some effects over and above the significance of a dynamic solution's degradation of positioning accuracy could be determined.

The accuracy results were consistent with the expectation of a 3 dimensional accuracy being worse than that of a 2 dimensional accuracy.

The poorer dynamic position accuracies would limit the efficiency of the applicator. Less soil nutrient variation than could potentially be catered for with static test positioning accuracies would be required. Literature does however indicate that dynamic accuracies are still suitable for what is considered to be highly variable K and P variations and would result in minimal product misplacement.

If uniform application across the applicator boom-width was employed, chemicals with short ranges of spatial dependence would not be able to be fully compensated for. As even dynamic accuracies are better than that of an applicator's boom-width, the upper limit on soil variability that can be catered for is determined by the length of the boom-width itself.

The dynamic accuracies calculated in these tests could be unsuitable for the acquisition of harvesting data. This possibility calls for a study into post processing techniques for the dynamically logged positioning data. In light

of these position post processing techniques, the exact positioning accuracy requirements for yield mapping needs to be determined.

5. DGPS proved very reliable for the soil sampling phase of the project. The use of GIS principles in the soil sampling was demonstrated. The calculation of semivariogram data provided insight into the soil variability that exists within typical fields. It was shown how the soil variability could be used to determine the position accuracy requirements of the SVFAP. Soil variability also gave an indication of what soil sampling intensities are required.

The Kriging interpolation technique provided more detailed soil information. Detailed soil information will result in more accurate fertilizer recommendations being made. Interpolated data is necessary for the generation of management grid cells. The size of each cell is determined by the applicator boom-width in the case of uniform application across it.

Chapter 8

Feasible Future Project Developments

This chapter describes topics and ideas that may warrant further research. Project developments subsequent to this report are described and the future plans for the project are related.

8.1 Topics for Future Research

Topics deserving further investigation are:

1. Agronomic strategies for the determination of fertilizer recommendations and yield-soil correlations. With regard to yield-soil correlations, deterministic models, prioritising and selecting certain yield affecting criteria, may be worth investigation.
2. Analysis techniques required by agronomists for the implementation of site specific practices. Statistical approaches and strategies for the development of the yield maps are continually changing and this research needs to be monitored. Various references provided in this document could be useful in this area.
3. The use of remote sensing for assessing the crop yield variations. This is a topic of intense research and needs to be monitored for its potential applicability to this work. It may also be worthwhile in keeping a look-out for advancements in the determination of other soil properties (such as soil depth and soil type, soil dielectrics, moisture etc.). Ready access to this

information would greatly ease the soil data collection requirements of this project.

4. Commercial software developments. A GIS based/expert systems software package would greatly assist the fertilizer recommendation process. Crop yield mapping software and software to generate GPS corrections in non real time may still be useful to this work.
5. The use of 'real time' sensors and on-board analyzers for the soil sampling process. With the emergence of various 'real time' agronomic sensors, their possible inclusion into the temporally separate implementation should be considered seriously. Accurate localized information relating to nitrogen and organic matter and soil moisture levels in the soil could be of great benefit. Although the technology of using the system in an automatic implementation is still not technologically feasible, an automatic nitrogen application could be considered to operate in conjunction with the temporally separate solution. In this case the temporally separate implementation could service the other fertilizer requirements.
6. The automatic application of herbicides through real time organic matter sensing (See Section 3.3). Although this field is not related to fertilizer application it may be useful in extending the functionality of the applicators.
7. The extension of the yield analysis system the detection of weeds and the production of weed infestation maps as described in Section 2.3.2.
8. The potential use of this spatially variable agricultural technology in the controlling of pesticides or seed distribution. Even spatially variable tillage has been proposed to operate as a function of land relief. Real time applications could include the spraying of weed infestations using camera equipment or the varying of planting depths as a function of moisture content.
9. An automatic guidance system for the different vehicles (especially the applicators). This is considered to be an extension to the basic project requirements. This development would require advance control techniques.
10. Avenues for the sensing of other variables of interest. Examples of this could include the need for sensing soil moisture content, external weather conditions or weed infestations as the vehicle makes a single pass over the field.

8.2 Recent SVFAP Developments

For as long as the major emphasis of this work is on the engineering developments, all tests will be carried out on the same field and each of the soil sampling, crop yield mapping and fertilizer application phases of the project will be engineered in isolation.

A method of obtaining mapped yield measurements needed to be implemented before last November's harvesting season. Similar to the sampling phase, the acquisition of real yield measurements had to be implemented to prove the suitability of the SVFAP design under these conditions.

The use of suitable statistical and data presentation techniques were established. Post processing software was used in order to determine the harvester's actual position at which the yield information was gathered. Yield information was also adjusted according to a model of the harvester's dynamic operation. Yield-position pairs were determined through the interpolation of the positioning information. Due to success achieved during this *harvesting phase*, it has been decided that this phase of the project be implemented commercially and the black box for the SVFAP is being developed. The results of these tests have not been included in this document.

8.3 Future of the SVFAP

The next steps in the implementation of this project are proposed as follows:

1. A technology update: Take time to peruse the most recent literature obtained from a visit to the USA (See Appendix K) and local sources.
2. Follow through on yield results: Visit with the farmers and agronomists so as to assess the causes for yield variations. The suitability of the graphical representations of the yield maps and the analysis techniques used for map generation, needs to be established.
3. Collect soil information: Based on these results the sampling strategy should be implemented in deciding where, in a typical application, intensive sampling should be carried out.
4. Generate soil sampling statistics: Perhaps some soil sampling statistics of these areas could be implemented to further evaluate the suitability of the engineering solution to the sampling phase. Experimentation with various

map configurations for best exposing yield variations, may be worthwhile. Perhaps the soil samples taken before the harvest and displayed in this report, should be correlated with the yield results over the same area as an academic exercise.

5. Implement the yield phase as a commercial service: This implies having the yield meter updated with the new software and a 'hill-side kit'. A robust black box hardware configuration, adaptable to the soil sampling and application phases of the project, needs to be established and commissioned.
6. Applicator Evaluation: As a start to the evaluation of the suitability of the rate control on the fertilizer applicators for SV application, the results of a flow meter upgrade for feedback control (to replace the pressure meter configuration) is of interest. The details of the new control techniques implemented on the applicators will be investigated and testing will also be carried out on the applicators. This could entail the modelling of the applicator process. Application should also be carried out on site in the real environment to test its effectiveness. A simulation with water and tank levels on site could be an option.
7. Applicator Investigation: The latest application techniques should be investigated including the possibility of mixing fertilizers on-board the applicators.
8. SVFAP Implementation: Beginning with the harvesting season next November, it may be possible to implement the SVFAP on a number of fields. The chronological implementation of the SVFAP's harvesting, soil sampling and fertilizer application phases may help in establishing comparative *agronomic* results. This would amount to the final testing of the effectiveness of the system and facilitate the decision as to whether to implement all three phases commercially.

Bibliography

- [1] Changing fertilizer blends on-the-go. *Progressive Farming*, March 1986.
- [2] H. Auernhammer. Requirements for a standard for tractor-implement communications. In *1993 International ASAE Winter Meeting*, pages 1 – 7, December 1993.
- [3] H. Auernhammer. Yield measurements on combine harvesters. In *1993 International ASAE Winter Meeting*, pages 1 – 8, December 1993.
- [4] H. Auernhammer, T. Muhr, and Weihenstephan. The use of GPS in agriculture for yield mapping and tractor implement guidance. *American Society of Agricultural Engineers*, pages 455 – 465.
- [5] Colin Beatty. Precise navigation with GPS. In *Third Workshop on GPS for Navigation and Surveying*, pages 1 – 6, February 1994.
- [6] L.E. Bode, J.W. Hummel, and Y.J. Han. Controlling chemical application rate with bypass spray nozzles. *American Society of Agricultural Engineers*, 29(5):1221 – 1227, October 1986.
- [7] S.C. Borgelt, Stuart J. Birrell, and Kenneth A. Sudduth. Crop yield and soil nutrient mapping. In *1993 International ASAE Winter Meeting*, pages 1 – 18, December 1993.
- [8] S.C. Borgelt, Stuart J. Birrell, and Kenneth A. Sudduth. Crop yield mapping using GPS. In *1993 Mid-Central Conference*, pages 1 – 18, April 1993.
- [9] S.C. Borgelt, Stuart J. Birrell, Kenneth A. Sudduth, and John D. Harrison. Global positioning system applications for site-specific farming research. In *1992 International ASAE Winter Meeting*, pages 1 – 14, December 1992.
- [10] Eshel Bresler and Gedeon Dagan. Variability of yield of an irrigated crop and causes:1 statement of the problem and methodology. *American Geophysical Union*, 24, pt.3:381 – 387, 1988.

- [11] Daryl D. Buchholz and Nyle C. Wollenhaupt. Managing field soil fertility variations. *University of Missouri - Columbia*, pages 40 – 44.
- [12] D. Carlson, P.M. Carr, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. Farming soils, not fields: A strategy for increasing fertilizer profitability. *Journal of Production Agriculture*, 4(1):57 – 61, March 1991.
- [13] Tom Hillyer. Field diagnostic kits proliferate. *Solutions*, pages 30 – 31, April 1992.
- [14] J.W. Hummel, Dohn W. Pfeiffer, and Norman R. Miller. Real-time corn yield sensor. In *1993 International ASAE Summer Meeting*, pages 1 – 25, June 1993.
- [15] J.W. Hummel, Marvin J. Pitts, and B. Jack Butler. Transient behavior of bypass flow nozzles. *American Society of Agricultural Engineers*, 29(3):718–722, 1986. Transactions.
- [16] Michael H.B. Jensen. Quality control for differential GPS in offshore oil and gas exploration. *GPS World*, pages 36 – 48, September 1992.
- [17] John Deere. *Operation and Repair Manual for the John Deere 9600 Combine Harvester*, 1992.
- [18] D. Keller. Make detailed fertility maps and call me in the morning. *Progressive Farming*, pages 84 – 85, January 1991.
- [19] R. Kinkel, D.J. Mulla, and A.U. Bhatti. Methods for removing spatial variability from field research trials. *Advances in Soil Science*, 13:201 – 213, 1990. Springer-Verlag 1990.
- [20] D. Little. Trends in application technology. *Solutions*, 34(7):66–68, December 1990.
- [21] C.L. Merry. *Introduction to the Global Positioning System*, volume 3rd Ed. Department of Surveying, University of Cape Town, Private Bag Rondebosch, January 1991.
- [22] D.J. Mulla. Soil spatial variability and methods of analysis. Sabelian Center, Miamey, Niger, Patancheru, AP.502-324, India. International Crops Research Inst. for the Semi-Arid Tropics.
- [23] D.J. Mulla, J.G. Annandale, G.S. Campbell, and A.P. Mallawatantri. Spatial non-uniformity in chemical leaching under irrigation. In *1991 International ASAE Winter Meeting*, pages 1 – 11, December 1991.

- [24] D.J. Mulla, A.U. Bhatti, M.W. Hammond, and J.A. Benson. A comparison of winter wheat yield and quality under uniform versus spatially variable fertilizer management. *Elsevier Science Publishers B. V.*, 38:301–311, 1992.
- [25] D.R. Nielson and J. Bouma. Transect sampling for reliable information on mapping units. In *Soil Spatial Variability: Proceedings of a Workshop*, pages 150–163, Wageningen, Netherlands, January 1985. Centre for Agricultural Publishing and Documentation.
- [26] Prof. Ron Palmer. Positioning requirements for in-field spatial variability. Number 90-1622, pages 1 – 10. American Society of Agricultural Engineers, 1990.
- [27] Eileen M. Perry. Using GPS in agricultural remote sensing. *GPS World*, pages 30 – 36, August 1992. Remote Sensing Research Laboratory.
- [28] Carolyn Petersen. Precision GPS navigation for improving agricultural productivity. *GPS World*, pages 02 – 08, November 1991.
- [29] Charles L. Peterson, Bin He, Geoffrey J. Shropshire, and Keith B. Fisher. A spatially variable management system for the application of fertilizer for the production of winter wheat in the Palouse. In *1993 International Off-Highway and Powerplant Congress and Exposition*, pages 1 – 15, 400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A., August 1993.
- [30] J. L. Pringle, M. D. Schrock, R. T. Hinnen, K. D. Howard, and D.L. Oard. Yield variation in grain crops. In *1993 International ASAE Winter Meeting*, pages 1 – 10, December 1993.
- [31] D. Du Rant. *Slimjan Beheerstelsel - Model M1000 - Gebruikershandleiding*. Kiberlab (edms) bpk, 1988.
- [32] John K. Schueller. Machinery and systems for spatially-variable crop production. Number 1 88-1608, pages 1 – 12. American Society of Agricultural Engineers, 1988. Transactions of.
- [33] John K. Schueller. Spatially-variable fluid fertilizer applicator design concepts. *Journal of Fertilizer Issues*, 6(4):100–102, 1989.
- [34] John K. Schueller. Design for dynamic response of sprayer-applicators. *Journal of Fertilizer Issues*, 8(3):69 – 73, 1991.
- [35] John K. Schueller, Y.H. Bae, S.C. Borgelt, and S.W. Searcy. Determination of spatially variable yield maps. Number 1, pages 1 – 17. American Society of Agricultural Engineers, 1987.

- [36] John K. Schueller and RS Kulkarni. Design of fertilizer application hydraulics with the LSU SSFAN software. *American Society of Agricultural Engineers*, (1 88-1594):3 pp, January 1988.
- [37] J.A. Schumacher and D.P. Froehlich. Computer controlled chemical application in controlled traffic fields. Number 89-1606, pages 1 – 25. American Society of Agricultural Engineers, 1989.
- [38] S.W. Searcy and Joe W. Tevis. Communication requirements for variable rate applications. Number 91-3030, pages 1 – 9. American Society of Agricultural Engineers, 1991. an ASAE Meeting Presentation.
- [39] S.W. Searcy and Joe W. Tevis. Generation and digitization of management zone maps. Number 91-7048, pages 1 – 16. American Society of Agricultural Engineers, June 1991. Mtg.New Mexico, 1991.
- [40] Richard T. Sharpe. The magnavox 4818 all-in-view differential GPS reference station: Description and test results. pages 1 – 12, London, 1989. Magnavox.
- [41] Marvin L. Stone and Mark Zachos. Application of J1939 networks in agricultural equipment. In *1993 International ASAE Winter Meeting*, pages 1 – 24, December 1993.
- [42] Joe W. Tevis, A. Dale Whittaker, and Darrell J. McCauley. Efficient use of data in the Kriging of soil pH. Number 91-7047, pages 1 – 17. American Society of Agricultural Engineers, June 1991. Mtg.,New Mexico, 1991.
- [43] Willie Vogt. Soil sensors boost management precision. *Solutions*, pages 26 – 27, April 1992.
- [44] LE Wagner and M. D. Schrock. Yield determination using a pivoted auger flow sensor. *American Society of Agricultural Engineers*, (87-1516):pp 15 – 18, 1987.
- [45] Steven C. Young, David G. Skokol, and Richard P. Strosser. Utilization of CAN technology in a distributed control system. In *1993 International ASAE Winter Meeting*, pages 1 – 13, December 1993.

Appendix A

List of Abbreviations

ASAE American Society of Agricultural Engineers

C/A Coarse Acquisition

D/A Digital to Analogue

DAU Data Acquisition Unit

DCE Data Communications Equipment

DCS Distributed Control System

dGPS Differential Global Positioning System

DOP Dilution of Precision

DTE Data Terminal Equipment

DTL Data Transmission Link

GDOP Geometric Dilution of Precision

GIS Geographic Information Systems

GPS Global Positioning System

HF High Frequency

HOW Hand Over Word

LNA Low Noise Amplifier

LOS Line of Sight

LU The formulation of a matrix to its Upper and Lower triangular equivalent matrices

MCS Master Control Station

MP Multipath

OCS Operational Control Station

OOP Object Orientated Programming

P Code Precise or Protected Code

PDOP Position Dilution of Precision

PPS Precise Positioning Service

PRN Pseudo Random Noise

QC Quality Control

RF Radio Frequency

RTCM104 The dGPS standard differential correction string

S/N Signal to Noise

SA Selective Availability

SPS Standard Positioning Service

SV Spatially Variable

SVAPS Spatially Variable Agricultural Production Systems

SVFAP Spatially Variable Fertilizer Application Project

TLM Telemetry Word

UART Universal Asynchronous Receiver Transmitter chip

UHF Ultra High Frequency

US DoD United States Department of Defence

UTC Co-ordinated Universal Time Reference

VHF Very High Frequency

VLBI Very Long Baseline Interferometry

Appendix B

GPS Principles

As described, GPS is the most feasible positioning technique to be implemented. This section describes some of the relevant GPS principles as this knowledge is required in order that a GPS system can be most effectively utilized. Many of these principles are described more comprehensively in [21].

B.1 Introduction

When considering positioning by means of satellites, various systems have been developed. These systems determine the position of a point on earth by measuring different parameters relating to the orbiting satellite; such as direction, range or range rate. The techniques used to obtain these measurements also vary.

TRANSIT or SATNAV, for example, is a satellite system developed by the US Navy for navigation and positioning functions. This system employs the technique of measuring the doppler shift from the orbiting satellite's transmitted signals. This technique is popular and is employed by various other systems including ARGOS, SARSAT and Starfix. Due to the limitations of this technique and the system configuration (i.e. the number of satellites and limited satellite viewing time), TRANSIT requires several days of integrated measurements to obtain a position within a 5m accuracy. This may have applications in the surveying fields but for 'real time' applications the best that can be done is a position with a 200m resolution in 10 to 20 min.

For real time positioning, the pseudo ranging technique employed by the GPS (American) or Glonass (Russian) systems has proven to be the most promising. This chapter was aimed at introducing the basic principles of GPS and some of

the theory which may be relevant to its effective implementation.

B.2 GPS Applications

There are many ingenious ways that GPS can be utilized. The fundamental applications, however, are for three dimensional positioning, accurate time referencing or for velocity measurements. Exactly how these features become available can be inferred from the following discussion of the principles of GPS.

B.3 Background

Surveyors have established a so called ‘geodetic network’ in which positions of points on the earth are defined. The network has an initial point obtained by astronomical means and is ‘point positioned’ in co-ordinates with respect to the geo-centre (centre of gravity of the earth). All further points in the network are obtained through ‘relative positioning’ techniques using line of sight (150 km) measurements.

Positions can be described according to various co-ordinate systems. The general form of the point definition can take on the cartesian (xyz) format or have parameters relating to an ellipsoidal definition.

Relevant co-ordinate systems for our purposes are the:

- Geodetic: This system can be described in either cartesian or ellipsoidal formats and is a national or regional system. The ellipsoidal form describes a latitude (φ) and longitude (λ) and ellipsoidal height (h).
- Gauss Conform (Lo): The South African plane co-ordinate system.

Datums in geodesy are described in geodetic co-ordinates which in turn are uniquely tied to the national geodetic network. The horizontal datum describes the size, shape and position of the ellipsoid (used for the geodetic co-ordinates) with respect to the geo-centre. The third ‘h’ co-ordinate refers to the ellipsoidal height measured on the outward normal. As this can not be measured accurately, mean sea level defines the new reference for ‘h’ and is called the geoid. The geoid defines the vertical datum and is necessary because the ellipsoid and geoid are not spatially coherent but are instead defined by a geoidal undulation (N) defining their separation at any point.

National datums have been defined over the years and do not generally match to the globally best-fitting datum. Such datums usually have an initial point at which it is assumed that $N=0$ and whose ellipsoidal centres are not geocentric.

South Africa's horizontal datum is called the Arc or the Cape Datum. The vertical datum is called the Land Levelling Datum (LLD) and is approximately 80 years old.

The time-varying position of the satellite is known as its ephemeris. Satellites stay in orbit by means of the earth's gravitational field. A satellite is given an initial acceleration sufficient enough to propel it to a height at which the centrifugal and gravitational forces will balance out. Orbits about an 'ideal earth' (spherical, uniform gravitational field, no atmosphere) have been described by Kepler and are called Keplerian orbits. Keplerian orbits define six orbital elements in the orbital co-ordinate system.

Satellite orbits are subject to perturbations due to varying earth gravitational fields, 'third body forces', solar radiation pressure etc. Some of these effects can be modelled and accounted for. The earth's gravitational field, for example, is affected by earth flattening and density variations. These effects can be modelled in a so called spherical harmonic representation (a two dimensional fourier series). The model requires the setting of the coefficients of such a model. The latest formalization of co-ordinate choice and gravitational model was developed by the US Dept. of Defence and is called the World Geodetic System 1984 (WGS84).

Despite these models, all elements affecting perturbations could never be modelled exactly and predicted orbits degrade rapidly. This is mostly due to solar radiation pressure and earth albedo.

Taking a measurement of the position of a point by satellite can be made in a particular co-ordinate system. It could then be transformed to geodetic co-ordinates in accordance with the relevant datum and thereby linked to the existing control (geodetic) network. All this should be done with regard to a specific formalization of co-ordinate choice and gravitational model (such as the WGS84).

B.4 The principle of GPS

The essence of satellite positioning is illustrated in Figure B.1 where the j 'th point's position R^j is determined from measurements to the i 'th satellite by the expression...

$$R^j = R_i - \rho_i^j \quad (\text{B.1})$$

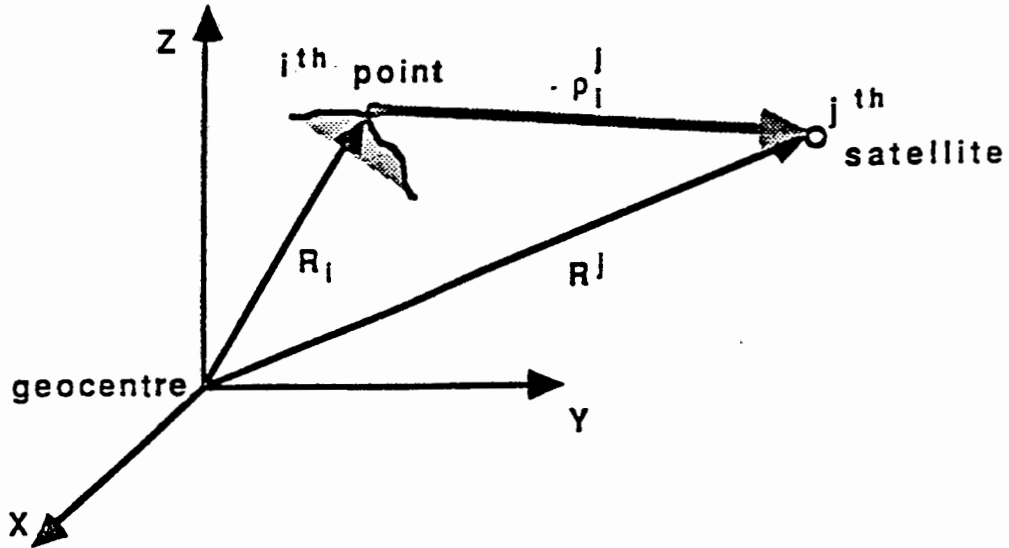


Figure B.1: The geometry of satellite positioning

The basis of the GPS technique assumes that the position of the satellite is known at any one time as well as that its clocks are synchronized with those of the other satellites and the receiver.

The technique entails transmitting a microwave signal from the satellites which are modulated with a complex time code and navigation message. The receiver generates an identical time code synchronous with that of the satellite. The received code is matched with the generated code at the receiver for maximum correlation. The time delay Δt_i of the transmitted signal is inferred from the correlation procedure. From this the 'pseudo range' $c * \Delta t_i$ is inferred. The navigation message contains, amongst other things, the time at which the satellite transmitted its signal. This is used to determine the error in the synchronization between the satellites and the receiver δt . The actual range from the i 'th satellite at a point say (p) on the earth's surface is then determined from the pseudo range by:

$$\rho_i = c * \Delta t_i + c * \delta t \quad (\text{B.2})$$

The position of the point 'p' can then be inferred by a tri-lateration process using

the known co-ordinates of the satellite contained in the navigational message. This technique is indicated by rewriting equation B.1 in terms of:

$$\rho_i = \sqrt{[(x_p - x_i)^2 + (y_p - y_i)^2 + (z_p - z_i)^2]} \quad (\text{B.3})$$

Where $i = 1, 2, 3, 4$ is the satellite number used in the measurement. Four satellites are used in any one measurement to obtain the three components (co-ordinates) of the required position and the fourth 'nuisance' unknown δt . These four unknowns are required for the solution of the four implicit equations in the combination of equations B.2 and B.3 for the solutions to p's position and δt .

B.5 The GPS System

The GPS satellites orbit at an altitude of 20000 Km and have an orbital period of about 12 hours. There are a group of satellites called the Block 1 or developmental satellites and are in an orbital plane of about 63 degrees to the equator. The Block 2 or operational group, orbit in a 55 degree orbital plane. The aim is to achieve three dimensional continuous positioning capabilities throughout the globe (i.e. having 4 satellites visible and above the horizon at all times). The space segment of the GPS system is comprised of 24 satellites, 21 of which are operational at any time.

The satellites themselves transmit two frequencies L_1 at $154 * f_o$ and L_2 at $120 * f_o$ where f_o is 10.23 MHz. Either or both of these signals can be modulated with the codes and messages. The satellites also harbour 4 atomic clocks each (2 caesium and 2 rubidium) for accurate timing information. The satellites maintain clock synchronization with the other satellites. The satellites are also required to accept the information loaded up from the so-called upload stations and transmit the required time codes and navigational messages.

The user segment comprises of an antenna, receiver and a processor capable of generating the required codes and processing the incoming information to determine the position of the receiver.

B.6 The User Segment

In a little more detail, the user segment comprises of an omni-directional antenna coupled to the receiver section which pre-amplifies the signal (possibly a LNA)

for the RF stage. The RF stage is required to separate the navigational message from the time code and process them separately. This is done by means of a variation of digital and analogue circuits to amplify, filter, mix, match and detect according to the information required from the separate signals as described by conventional radar and signal processing circuitry. (The processing may be required for both carriers if they are accessible.) This treatment is required for the signals received from each visible satellite creating the need for the ability to lock onto and track each satellite individually. A strategy of multiplexing or separate tracking channels may be required for this purpose.

By means of an oscillator clock and various analysis criteria, the obtained information is processed to produce positioning information. There will also be a user interface enabling the user to select a specific co-ordinate system, datum or display mode. There may also be the facility to interface to another navigational system.

B.7 The Control Segment

The assumption that the positions of the satellites are known has to be catered for. This is achieved by 5 base stations which are used to track the satellites. These stations communicate with a master control station which manipulates the received data before sending it to 3 upload stations. The upload stations upload the parameters of the satellite ephemeris to the satellites once or twice a day. This configuration constitutes the operational control system (OCS).

The master control station (MCS) uses the WGS84 model used in orbit modelling in addition to the previous week's tracking information and the current satellite co-ordinate values to make an initial estimate of the expected ephemerides of the satellites. The MCS extrapolates the ephemerides and sends this data to the upload stations. In addition to these 5 tracking stations, other stations exist around the globe using pseudo ranging or doppler techniques to provide on-line corrections to the original ephemeris estimates. Some organizations also provide post-computed ephemeris data for the refinement of the results obtained from using GPS.

In addition to collecting and transmitting data relating to the satellite orbits, the base stations also monitor and upload information relating to the general 'health' of the satellites, the clock biases and drifts required for the satellite clock synchronization and the almanac data (i.e. abbreviated ephemeris data of all the satellites) which is required for the optimum selection of satellites above the horizon.

B.8 The Transmitted Signal

The microwave signals transmitted from the satellites are coded with a complex time code and a navigation message.

The time code is generated from phase modulating the carrier by a pseudo random noise (PRN) bit pattern of $+ - 1$ steps. There are two separate codes which are generated. One is the C/A or coarse/acquisition code and the other is the P-code or precise or protected code. The C/A-code repeats every millisecond and modulates the carrier at $f_o/10$ where f_o is 10.23 MHz. The P-code runs at the higher multiple frequency of f_o and only repeats every 267 days. It is also more complex, having different portions delegated to different satellites. The result is that the P-code is far more accurate than the C/A code.

The navigational message transmits the information obtained from the OCS relating to the satellite's position, its state of health and the current clock biases and drifts. In addition, information of the almanac of all the satellites is transmitted to facilitate the optimum selection of satellites above the horizon. To correct for inaccuracies in satellite and receiver clock synchronization, the satellite clock time of transmission is also included in the message. Finally, a reference ionosphere refraction correction model for systems working on only one frequency and the difference between GPS time and Co-ordinated Universal Time (UTC) is also included.

All this information is in a navigational message 1500 bits long. It is divided up into 5 sub-frames containing specific information at 50 bits per second. Some sub-frames only transmit part 'page' of the information required as the remainder is transmitted by the other satellites. The almanac data, for example, is split up into 25 pages (one page per satellite) and takes 12.5 minutes for all the information to be received. The so called telemetry word (TLM) and hand over word (HOW) also appears at the beginning of each sub-frame to indicate the status of the data upload and the sub-frame number and the Z count (indicating the satellite clock time at the instant of observation).

(Note that a correction model for troposphere errors may also exist for the associated biases.)

B.9 System Implementation

As the system was developed by the US Department of Defence, they have instituted two levels of system implementation. The standard positioning service

(SPS) is primarily designed for use by the civilian user. It uses the C/A code and makes only one of the two carrier frequencies available for modulation. This makes it more difficult for the removal of ionosphere errors. This service provided positioning information more accurately than the designed specifications and as a result, the US DoD introduced the 'selective availability' (SA) policy. This policy was to downgrade the system by placing a jitter on the satellite clock information and a coded bias on the satellite ephemeris parameters to which the US DoD has the 'key'. This level enables a positioning accuracy of 50m (1σ) even with SA.

The other level of implementation is called the precise positioning service (PPS) used only by the US military and makes use of the P-code modulating two carrier frequencies and capable of a positioning accuracy of 10m (1σ).

B.10 Range prediction

All the elements affecting a range measurement described in this chapter and catered for by the GPS system, must be used to modify the simplistic range prediction described in equation B.2. The new equation would look something like the following:

$$\rho_i = (c * \Delta t_i - c * dt_i - d_{ion} - d_{trop}) + c * \delta t \quad (\text{B.4})$$

Where dt_i , d_{ion} and d_{trop} represent the satellite clock corrections, the ionosphere refraction model corrections (in the instance when only one carrier is available) and the troposphere model corrections respectively. The expression in the parentheses is defined as the corrected pseudo range R_i . Combining this equation with equation B.3 defines an expression in which the unknowns x_p , y_p and z_p can be determined from the known co-ordinates of the satellite, the corrected pseudo range and the receiver-satellite synchronization error δt obtained from the Z count (see Section B.8). i.e.

$$R_i = \sqrt{[(x_p - x_i)^2 + (y_p - y_i)^2 + (z_p - z_i)^2]} - c * \delta t \quad (\text{B.5})$$

This form indicates that the point's co-ordinates and δt can be determined from the corrected pseudo range R_i from satellite i. As the satellites should be synchronized δt should be the same from each satellite for the position 'p'. Four unknowns require the interrogation of four satellites. To optimize the data the above equation can be linearized by a Taylor expansion and the method of least squares employed using matrix algebra. Using linear algebra theory, an estimate

of the suitability of the geometry of the position ‘fix’ can be determined from the calculation of the least squares method. This quantity is called the Dilution of Precision (DOP) and is described in [21] in more detail.

B.11 Differential GPS

Many applications require greater accuracies than those provided by the GPS operating in its standard mode of operation (i.e. point positioning using pseudo ranges). There are techniques available to improve the accuracies significantly (see the following section) for static observers. It is also possible to improve the accuracy of measurements in applications requiring real time positioning information using the differential GPS (dGPS) technique.

There are two common techniques of dGPS. Both techniques involve a receiver whose position is accurately surveyed and serves as a reference station (see Figure 2.2). The first of the two techniques involves the computation of the C/A-code positions at both the reference and the mobile receivers. The corrective co-ordinate shifts calculated at the reference station are then used to alter the measurements made at the mobile station. This technique requires little computation and little information is required for the correction of the mobile receiver’s position.

The alternative technique uses the broadcasted satellite ephemeris together with the known position of the reference station to compute the actual ranges to the satellites. The pseudo range measurements at the reference receiver is then used to determine the corrected ranges (ΔR) to be sent to the mobile station. The second technique is more accurate than the first but requires more correction data to be made available to the mobile receiver for correction. In the case of a real time operation where a data transmission link (DTL) is required for the transmission of the correction data to the mobile unit, a higher data rate will be required of the second dGPS technique.

(Note that dGPS can be used in non real time applications, therefore not requiring the DTL and operating on the data in a post-processing mode.)

The major cause of positioning errors are due to the unmodelled biases in satellite ephemeris data as well as the induced ephemeris errors caused by SA in the SPS. Other major causes of errors are the SA induced clock jitter effect and the inadequately modelled effects of refraction errors in the ionosphere. DGPS reduces these errors due to the fact that two positions close to one another are spatially coherent. This can be understood as two relatively close points on the earth’s surface being equally effected by the atmospheric properties above them in

receiving signals from a common satellite. In addition, these receivers will receive the same ephemeris errors (both real and induced) from the same satellite. Clock jitter can also be reduced if the differential corrections to the measured ranges are made at a fast enough rate.

It is important that both stations observe the same satellites. This becomes more of a problem when multiple mobile units are in operation or where the mobile units are more than a few hundred kilometres from the reference station.

Using dGPS, 2 to 5 metre accuracies can be achieved. The disadvantage of the technique however is increased cost through the addition of a reference station and a data transmission link. DGPS also reduces one of the other advantages of using GPS for positioning purposes in that the mobile station must be within line of sight of the reference station whilst still being in common view of the relevant satellite(s).

It has been said that dGPS can compensate for some of the effects of SA. The amount of correction required in each dimension can be represented by a standard deviation, average deviation or RMS. The amount of SA is determined by the number of satellites having SA turned on and the amount of correction required for each position dimension of the calculated position. The second order characteristic of the correction data is directly related to the required correction update rate. This is because of the distinctive relationship that exists between an excited second order characteristic in correction data and that of positioning errors that occur at a fixed correction update rate (see [40] for details of this observation).

B.12 Other Techniques

For scientists, surveyors and geophysicists, the 2 to 5 metre accuracy available with dGPS is not accurate enough. These users, however, have non real time applications of the GPS system in common. They also have the advantage that only relative measurements of positions are usually required.

In these applications, one technique called the differential carrier phase technique can be employed. In this case the C/A code is no longer used for correlation purposes. The sinusoidal carrier with a short wavelength of 20 cm is used in its place. The phase change of the received signal is used to infer the distance and the integral number of cycles of phase change can be determined by integrating the results over a suitable period of time. This technique also uses a reference receiver like the dGPS technique. Similarly to dGPS, this technique eliminates ionosphere and SA biases. Another configuration is to have only one receiver

tracking two satellites simultaneously. From this it can be seen that advanced receivers in differential mode and various post processing techniques are required for this implementation.

The measurements from these receivers improve the longer you allow the integrations to take place.

Based upon these phase resolution principles, surveyors invented further extensions to this technique. Kinematic surveying, for example, involves a mobile surveyor who can survey in different points, provided satellite lock is maintained. This is provided that the baseline is not lost (i.e. knowledge of the integer number of cycles represented in the phase difference).

Modern trends are to impose doppler and phase smoothing onto the GPS and dGPS pseudo range solutions. Accuracies around the 5m level are possible using these techniques. The use of a narrow code-phase correlator is a recent development. This algorithm facilitates the resolution of not only the code phase bit rate, but also the phase angle of each bit. Accuracies of the order of 50cm (1σ) can be achieved using these algorithms and can get as low as 30cm if a receiver has access to the P-code. The implementation of these algorithms together with all the hardware options available (see Section B.6), account for the large variation in receiver prices.

The very latest development, discovered at a conference earlier this year (see [5]), is that algorithms have been developed in which kinematic surveying techniques can be implemented for dynamic applications of dGPS position determination and navigation (i.e. carrier phase dGPS). The algorithms have the ability to resolve the integer ambiguities 'on-the-fly'. As a result, satellite lock need not be continuously maintained or the baseline re-established in the event of the loss of satellite lock and dGPS surveying accuracies (between one and ten cm) can be achieved for ordinary dynamic dGPS applications. These receivers will soon be extended to allow for real time position determination using these techniques.

B.13 GPS Quality Control (QC)

This is an aspect often overlooked in the business of location determination. The requirements of the consumer is very adequately stated in [16] in the case of the seismic oil and gas exploration industry. Some of these requirements for a dGPS configuration is for it:

- to provide sufficient details of the receiver algorithms to enable their integration with other observables in third party software.

- to provide quality control in terms of statistical testing in real time. This is usually achieved in terms of redundant observations facilitating overdetermined solutions and the calculation of statistical biases. Other techniques involving height-aiding algorithms or an on-board atomic frequency standard could be implemented to facilitate a redundant measurement. These techniques are elaborated upon in [16].
- to provide GPS range residuals, error figures (determined from a least squares based optimal estimation method), the satellites used, azimuth and elevation, S/N ratios, user defined range error at the reference station, DTL performance as well as PDOP figures as determined from the overdetermined solutions.

External quality control should be implemented by the user as much as possible. Ideally, two equivalent stand-alone primary positioning systems would provide operational integrity in the event that one fails. The use of two monitor stations (one within 50 km of the reference station) for information on transmission and spatial de-correlation would provide transmission integrity. An alternative to this latter suggestion is to use a network of reference stations each monitoring each other and providing a choice of reference stations for the user (as proposed for implementation in the U.K.). As for the reference station, it is desirable that the co-ordinates are calculated in WGS84 format and determined from very long baseline interferometry (VLBI) geodetic points. The mobile receiver should also determine its position in the same co-ordinate system to avoid compounding errors in datum transformations.

Other suggestions include the automatic re-booting of a reference station to load its setup data should power fail. For improved QC, the reference station co-ordinates should be transmitted in the RTCM message every hour or so.

A site health check should be carried out. This will usually involve installation at least 30 m away from any vertical structures to avoid multipath and the code and carrier data should be recorded for a 48 hour period to ensure that the standard deviations remain within the tolerances. Operators should check receiver filters at regular intervals. The exact method of reference site installation in this manner requires more definition. It would be useful if this test be carried out periodically and especially after a constellation change.

Another means of QC could be in the logging of raw data in real time for postprocessing. This would provide the facilities for determining biases for the assurance of accurate results and for the improvement on the real time results in certain applications. As the latter is the most likely implementation of dGPS data post-processing, the logging of phase smoothed pseudo ranges (as opposed to raw code measurements) should suffice. This is due to the fact that most of the possible

biases are due to elements that could be corrected through an adequate configuration of dGPS and a suitable operator installation and monitoring procedure.

B.14 Future Improvements

The feasibility of integrating other navigational systems, such as the DECCA or TRANSIT systems, into a system which might work in combination with the GPS system is being investigated. If GPS and GLONASS could be integrated it may result in many redundant satellites for improved system integrity. This research is taking the form of developing receivers to process signals from both GPS and GLONASS satellites.

Improvements to the MCS in order that they may warn the receivers of failures through the health status codes are being sought. This has become a necessity because of the hours of delay before the MCS warns the receivers of the fault. More research in the field of support integrity functions through companies like INMARSAT is being undertaken. The aim is to transmit warning signals in a near real time mode.

B.15 Conclusions

GPS is superior to previous satellite navigation systems in that continuous positioning information is available due to the satellites being continuously visible. A new position ('fix') is available every second as opposed to the other systems requiring a full satellite pass in order to obtain the same information. When coupled with doppler analysis techniques, this system can also provide reliable velocity information. For further information and details of GPS principles refer to [21].

Appendix C

Field Test Procedure

C.1 Preparation

In addition to the groundwork achieved in the pre-study, a fair amount of preparatory work had to be done prior to the testing of the SVFAP solution. This work was required for the experimental testing of the design, but would also apply in the implementation of the final commercial product.

The following preparatory work needed to be co-ordinated:

- The investigation of the various GPS configurations for hiring or buying purposes, the contracting of the surveyors, the advice and support of the farmer and his staff, the assistance of the agronomists and the analysis laboratory and other volunteered help had to be co-ordinated. The administrative arrangements with Kynoch's management also had to be made.
- The field tests had to be *planned and scheduled* according to everyone's requirements and decisions as to the procedures and places at which the tests would be carried out, decided upon.
- A fair proficiency in 'C' had to be achieved to develop the software that would enable the implementation of the field tests and the post processing of the obtained data. A print out of both those sets of software is available in Appendix Sections G.1 and G.2. Specifically the theory and software procedures required for interrupt driven serial communications had to be consolidated. This became necessary because the processing times required by the software were longer than the time allowed by the operational baud rates. For example, scrolling on the text screen caused data to be lost

at the serial port. Actually, graphics screens also became a necessity; for example, to better accommodate things like the viewing of the position calculation cyclic report on the screen. With the interrupt facility installed, such graphics screens could be used to indicate the results of the various tests.

- Some of the post processing required some statistics and interpolation techniques and the related theory for each of these requirements was consulted.
- The software and the system configuration had to be tested as thoroughly as was possible in the laboratory. The testing of the software involved simulating the data from a GPS receiver by means of another computer sending the string over a serial cable (This software is available in Appendix Section G.3). With access to the GPS equipment, getting the GPS system and the purchased notebook correctly configured to implement the software was also later implemented in the laboratory. The operation of the GPS equipment was described in manuals supplied by the equipment contractors.
- In addition to the post processing and test software that was developed, the Geographical Information Systems (GIS) package ARC/Info, was implemented on SUN Workstations and was useful for the representation, transforming and manipulation of the spatial data. Other software that was used included QuatroPro, Freelance Graphics, Multi-Edit, Surfer (3D graphs), LATEX, PIZZAZ, various C (recipes and libraries) and DOS utilities and XFORM (a co-ordinate transformation package developed by Prof. Charles Merry of the Surveying Department at UCT).
- It is necessary to note that the software developed for the purposes of these tests and the post processing of the data was functional and developed for these *specific* tests. The software was however modularized and can therefore be used in that capacity. A print out of the software is available in Appendix Sections G.1, G.2 and G.3.

C.2 Details of Proposed Testing Procedures

For the purposes of the field tests, it was decided that no enclosure would be provided for the equipment and that the loaned equipment would instead simply be strung together for this experimental phase. The specifications of the entire system will be re-assessed after the tests and the requirements of the commercial product defined.

Items on *loan* included the reference station in its entirety. This reference station could be powered from the homestead in the case of the dynamic tests, but would

have to be powered remotely at a high site on the farm for the testing of the differential link. The data transmission link (transmitter, receiver and modems) and the remote receiver, antenna and connections were also on loan.

On initially *setting up* the equipment and the link, the baud rates of the telemetry link should be suitably matched to accommodate the required correction update rate. The DTL and GPS receivers antennae require good horizontal sky view positioning and ground planes.

The *testing of the differential link* throughout the farmland requires careful planning ahead of time as to the where to place the reference station and where to take measurements.

Receiver tests include:

- Checking that the receiver tracks satellites right down to the horizon.
- The logging of positioning data whilst moving about the fields in complicated paths. This serves to check that an averaging algorithm hasn't been used to disguise inaccurate position estimations. Poor position estimations arise out of timing errors and slow calculating speeds. Such averaging algorithms are no good for dynamic real time applications, but are suitable in post processing algorithms to smooth out the data.
- Checking that the update rate is as quoted. The speed of calculation directly affects the dynamic solutions. An adequate measurement update rate was tested by logging positioning data in bringing the vehicle to a sudden stop.

Static tests should validate the quoted accuracy specifications. The test will basically comprise of placing the two receivers at two surveyed positions, 30m away from any vertical structures (so as to prevent any multipath errors) and recording positioning data for a substantial period (recommended 48 hour period). This test has been formulated as an attempt to eliminate all but the terrain independent errors to assess their effect. Reasons for obtaining an inaccurate position measurement can be due to a number of factors.

It is essential that the co-ordinates of the reference station are accurate and maintain that integrity throughout the duration of the exercises. It is also vital that the information passed via the DTL and the RS232 interface to the computer is not corrupted. In the former case this can be monitored by the indication of the loss of the differential corrections as the receiver ignores corrections that have failed the parity checks etc. that take place in the telemetry of the DTL. Similarly the UART can be programmed to ignore bad parity tests on the RS232 interface.

Other errors are those that may arise due to hardware failure and should present themselves as a matter of default.

If these errors are compensated for then it becomes possible to concentrate on the following causes of positioning errors:

Errors which can be detected and eliminated in a controlled testing environment are those which arise due to the loss of LOS with the satellites or with the reference station or other multipath errors. These are terrain dependent errors. Other spurious errors which can occur, could be due to increased SA levels and atmospheric conditions not completely compensated for by the models. The current geometrical configuration (PDOP) of satellites also has a direct effect on the quality of the positioning information.

Manufacturers have completed tests to prove that the differential solution removes the effect of SA. The degree to which this is effective at higher degrees of SA however has not been established. To complete these tests would require a-priori knowledge of SA levels or the logging of raw correction data for post processing. Such comprehensive testing is beyond the scope of this project as the aim is simply to establish the suitability of GPS technology. It will therefore be taken by faith that as previous tests have indicated, SA will not become a substantial difficulty in the differential solution. There is however a correlation between the correction update rate and the degree to which SA is removed. Update rates therefore, have to be carefully chosen.

In good weather conditions then, the only circumstances that needs to be monitored for its effect on position accuracies, is the effect of the satellite geometrical configuration and the number of satellites in view. It is therefore only left to determine the effect of different PDOPs and number of satellites in view on the standard deviations in position. Such tests will provide valuable information with regard to what maximum PDOPs can be tolerated and give some insight as to the frequency at which unacceptable PDOPs and constellation inefficiencies occur. GDOPs less than three are recommended for mission planning and accuracies within 10m. It is worth noting that there may not be an entirely direct relationship between PDOPs or number of satellites in view and positioning inaccuracies. This is due to inability of the system to totally compensate for the other spurious and indeterminable effects mentioned previously.

For the *dynamic tests*, a redundant positioning technique is required to serve as a reference for the positioning information obtained. The grid of way-points could serve this purpose in this instance.

It is proposed that the position is logged whilst approaching a way-point from two directions and then statically, directly on top of the way-point. The dynamic

solutions should be worse than the static one due to the limited speed of position calculations. The size of the circle formed by the three measurements is indicative of the measurement accuracy. Standard deviations can also be calculated from these results.

These tests will provide insight as to whether the implementation of the technology in the agricultural environment downgrades the system performance and whether or not the amount by which this occurs actually makes the limited accuracies available with a less accurate/complete receiver (the SVee6 for example) obsolete for our applications. It is necessary to do dynamic tests in a typical field for the purposes of establishing what percentage of the field's positioning information has been corrupted due to multipath, loss of LOS (either to the satellites or to the reference station) or other spurious terrain dependent effects. A good receiver should track weak signals and be capable of rejecting multipath. If there are any limitations of the positioning technique due to poor tracking conditions in this environment or due to a vehicle travelling at typical speeds, then these need to be established. These effects can be established through the occurrence of the loss of the differential link indication or erratic position solutions (indicated by impossible speed changes, by a graphical representation of the line of travel or positions that fall way out of the static accuracy specifications).

Should no multipath errors be apparent within the test field, then it may be worthwhile to simulate them in order that a parameter representing the occurrence of multipath or loss of LOS with the satellite can be established and used for detection in the real implementation.

To implement the *sampling phase*, the dimensions of the grid size needs to be decided upon. Map generation and post-processing software also needs to be utilized and developed.

C.3 Requirements for the Implementation of the Field Tests

The following was be required for the implementation of the field tests:

- A vehicle upon which to mount the equipment for the tests.
- Batteries for the powering of the remote reference station (if a vehicle could not be used in this case). Discussion with the equipment contractors to assess the availability of the remote powering for the tests requiring a remote reference station.

- Arranging with a surveying company to do the surveying of way-points ahead of time.
- Confirmation with the farmer that the plans and timing of the tests were suitable. Obtaining his permission for the equipment to be set up on his farm. His assistance with selecting suitable measuring sites was also valuable.
- The loaning of the dGPS equipment from equipment contractors for test purposes. There are certain standards of interface protocols and terminologies maintained throughout a make of GPS receivers making the transition from the set on loan to a purchased set out of the same range a little easier.
- The use of a sampling car and the assistance of the agronomists for the implementation of the sampling phase.

For the final implementation of the technology, should the tests prove successful, the following adaptations will be made to the system used in the tests: (Details of these design criteria have already been discussed)

- Improved quality control with the possible inclusion of a half hour transmission to the remote station of the reference co-ordinates and a means to reboot the reference station on power down.
- Include an operator interface to enable the initialization and running of the program by the operators.
- These latter two requirements necessitate that the receiver selected can be remotely controlled so that the program can run like a black box to the operator.
- Adapt the system to be able to include many other inputs (such as speed and yield measurements) for the implementation of all the phases of the project. This requires improved interfacing and communication facilities.
- Arrange for a more permanent and environmentally sound enclosure for the equipment.

C.4 Field Test Description

The Figures referred to in this Appendix are presented in the main body of the thesis in Section 4.4.

The menu-driven software used for the processing and logging of the relevant information during each test is provided in Appendix G.1. The following is a description of the events which took place:

DAY-I The surveyors began the positioning of points on a 100m grid in a selected field (see Figure 4.5 and Figure 4.6).

The aim was to obtain 3 dimensional point positions in the WGS84 surveying datum. Positions were to be represented in latitudes and longitudes (geographical system) to be synonymous with the position representations used by the GPS. The height data was to be determined in relation to the international best fit ellipsoid (i.e. Ellipsoidal heights) again in sympathy with the system used by GPS technology. Whilst the surveyors were staking out the field, the possible reference points were assessed for their suitability. The choice of reference positions were based upon their relatively high altitudes as indicated by the orthophoto maps of the area. One ideal remote point with mains power running to it, had to be disregarded due to the interference of tall trees within 30m of the reference point. It was decided that the trig beacon would serve adequately as a *typical* choice of reference station on this particular farm. Another point was surveyed on the farm homestead for use during the 'dynamic field tests' as it would enable the system to be powered from mains. This point could possibly also have served as a suitable reference point for the entire farm, considering the power and range of the DTL.

DAY-II The surveyors continued with the grid formation and processing of data into the desired datums whilst some last minute software changes, preparations and arrangements for the commencement of the following day's tests were made. The surveyors surveyed in the 9 extra points on the road next to the trig beacon for the purposes of the 'terrain independent dynamic road tests'.

DAY-III Based on previous discussion, no mission planning or logging of the correction data string took place. The latter consideration was vetoed because of the relatively small distances between the GPS receivers (Max 10km). The reference station was set up at the trig beacon. The satellite and omni-directional DTL antennae were attached directly to the trig beacon and the equipment placed inside a vehicle for protection (See Figure 4.7).

For this first day of tests, two 12V car batteries were used in parallel for power. The GPS receivers were programmed with the reference position, satellite exclusion mask angle, position update times and

position fix modes etc. (See Appendix H for a print-out of the receivers operational modes). The antennae were then rigged onto the Land Rover and the equipment set up inside it in preparation for the differential link tests. The GPS receiver and notebook was powered via the 12V battery under the passenger seat and via the cigarette lighter respectively (See Figures 4.8 and 4.9).

The system was tested by taking a reading at another surveyed point on the road close to the beacon. The *differential link tests* or DTL tests entailed maneuvering as far as was possible, to the outskirts and to areas of the farm that contour maps had indicated would probably have difficulty in maintaining DTL connections (See again Figure 4.8). Positioning information was logged.

DAY-IV The reference station was again set up at the trig beacon but was powered from a Yamaha generator working through a charger to two 12V batteries (See Figure 4.10).

The soil had dried sufficiently from the recent rains to venture onto the fields with the Land Rover and as the 'sampling tests' had to be done before the weekend (and any more possible rain) samples were taken on an approximate 30m grid on the selected field (See Figure 4.11).

The area chosen looked fairly homogeneous in nature according to the agronomist and 3 rows of six samples were taken. The remaining 4 rows were marked off by driving stakes into the logged positions for later sampling (See Figure 4.12).

Each sample's position was logged for approximately 2 minutes.

DAY-V With the reference station again set up at the trig beacon (This time powered via the generator through a power supply with a sufficient current rating), the 'terrain independent dynamic road tests' were carried out. The remote GPS receiver was re-programmed for a faster update rate of position calculations for these dynamic applications (a printed output of the configuration of the receiver is available in Appendix H). In order for these dynamic tests to be carried out, a horizontal stake was tied to the front of the Land Rover and was used as a means of logging the flagged way-points on the road (See Figure 4.13 and look ahead to Figure 4.20).

The stake was tied to both the left and the right hand sides of the vehicle to do the dynamic tests approaching the way-points from both directions. The dimensions and test set up are indicated in Figure 4.14 and Figure 4.15.

The positions of the way-points were also logged statically for comparative purposes (this form of dynamic receiver tests and that of the

standard receiver tests (to follow), is based on the recommendations laid out in Trimble's '*How to test drive your GPS receiver*' booklet.

Some of the other standard 'receiver tests' were then carried out through the monitoring of the receivers and the logging of the position data whilst bringing the vehicle to a sudden stop. The latter test is aimed at establishing whether or not an averaging algorithm has been implemented to disguise poor position calculations or update rates that are not as quoted by the manufacturers. Poor position calculations could result in a poor dynamic response. This latter test was implemented by logging a position on either side of the road to serve as a 'finish line' and then to log position data whilst approaching it slowly and then again whilst approaching it quickly (50km/h) before coming to a stop. The software logged the overshoot that occurred.

Finally positioning data was logged at predetermined places within the farm. These positions were thought to represent places that could exhibit various terrain dependent effects (constituting the 'terrain dependency tests') such as: possible multipath effects, loss of lock on satellites and loss of DTL corrections. These tests were achieved using the 'dynamic test' option of the test software.

DAY-VI The reference station was set up at the homestead reference position on top of a little dam (See Figure 4.16).

The closest building at the height of the satellite antenna was approximately 20m away and not high enough to interfere with the unmasked sky space designated for satellite tracking (See Figure 4.17). The reference receiver had to be re-programmed and a copy of the output describing its new configuration is in Appendix H.

The reference equipment was set up inside a little room containing farming chemicals where mains power was accessible (See Figure 4.18) and the DTL/Telemetry antenna was fixed to the gutter outside the room (See Figure 4.19).

In preparation for the *field dynamic tests*, the corners of the field were logged using dGPS and the position of one of the surveyed points within the field was checked to see if it correlated with the dGPS reading for the new set up (See Figure 4.20).

The *field dynamic tests* were then carried out similarly to the *terrain independent road dynamic tests* (first logging positions statically and then dynamically with the horizontal stake attached to the right hand side of the vehicle only: Dimensions provided in Figure 4.21).

Finally, data was logged on the far side of the field close to some trees that could have caused some satellite lock or multipath problems (as part of the 'terrain dependency tests'). This data was tagged by the software for later analysis and was taken to be indicative of terrain dependencies in a typical field. At the end of the day, the mobile station was removed from the Land Rover and placed inside the room containing the reference station (See Figure 4.22).

The 'mobile' station's satellite antenna was set up next to the satellite antenna of the reference station (See Figure 4.23) and the telemetry antenna was left inside the room.

This configuration worked adequately with the reference telemetry antenna, strapped to the gutter outside, linking well with the one inside. The 'static test' was implemented to test the nature of the corrected position information as a function of the various terrain independent parameters thought to affect the performance of GPS accuracies. The position of the reference station (and therefore also of the mobile station) was known but only the reference station was providing corrections to the mobile station's readings based on that knowledge. The 'static test' was invoked and left to run overnight; logging the necessary data from the static 'mobile' station.

DAY-VII The equipment was switched off and the final data files backed up late in the afternoon after 24 hours of logging had taken place.

DAY-VIII Arrangements were made to return all the borrowed equipment to the university, Underwater Surveys and to the farm. Outstanding amounts were paid and the final photographs and notes were taken.

Appendix D

Dynamic Test Measuring Technique Compensation and Accuracy Determination

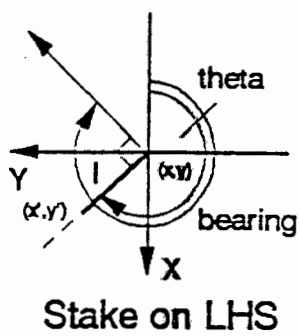
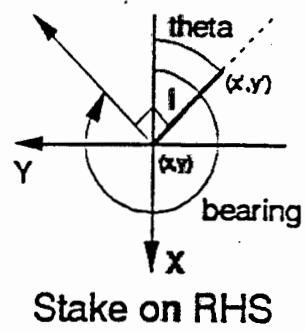
This appendix has been included to show how the dGPS dynamic accuracies were determined. The positions against which the dGPS positioning information was measured, served as the reference positioning technique. The inaccuracies with which these reference positions were measured need to be taken into consideration in the determination of the dGPS position accuracies.

D.1 Measuring Technique Compensation

The inaccuracies associated with the technique used to measure the reference positions need to be determined.

In the first instance, compensation for the displacement of the measuring point away from the antenna needed to be made. What was required was that the post processing software extract the tagged position records (indicating a waypoint measurement) from the logged records and transform it to Gauss Conform co-ordinates (metres). This information combined with a file containing bearing data extracted from the same records, was used for the compensation shifts. These shifts can be best explained by means of a diagram: Figure D.1.

According to the diagrams, the shifting of the position fix from the position of the antenna to the position at the end of the stake, can be achieved by the following formulae:



Stake : Length (l)

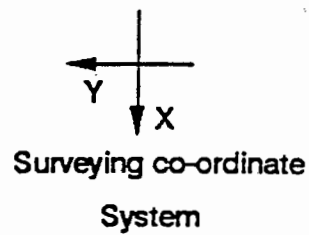


Figure D.1: Using the bearing data to compensate for the displacement of the measuring point from the antenna

$$\begin{aligned}
\theta &= \text{bearing} + 90^\circ && \text{for the RHS} \\
\theta &= \theta - 360^\circ && \text{if } \theta > 360^\circ \\
\theta &= \text{bearing} - 90^\circ && \text{for the LHS} \\
\theta &= \theta + 360^\circ && \text{if } \theta < 0^\circ \\
\Delta x &= l \cos \theta && \text{and} && x' = x - \Delta x && (D.1) \\
\Delta y &= l \sin \theta && \text{and} && y' = y - \Delta y && (D.2)
\end{aligned}$$

It was discovered that the North of the WGS84 datum varies from that of the SA datum as a function of distance from the 19° longitude reference used for the transformation to gauss conform co-ordinates (See Figure D.2). The concern was that bearing information did not undergo any transformation process and would therefore introduce errors into the compensation that would destroy the benefit achieved by the previous formulae. It was estimated that the difference between the two Norths was about 15 minutes in this area and would therefore result in an arc length error of about 8.7mm (θr) with a two metre long stake. This is negligible to the stake length.

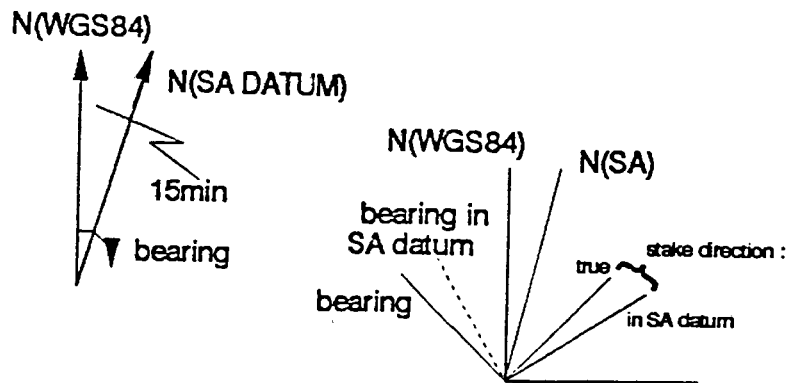


Figure D.2: Effects of a different datum on bearing data

Figure D.3 indicates how the compensation can result in the measurement moving closer to or away from the actual surveyed position. If the GPS calculated position was in the RHS of the GPS accuracy circle, the compensated position would move away from the actual surveyed position and visa versa. Nonetheless, the compensated point will be a closer representation of what the receiver would have shown had the antenna been placed at the end of the stake.

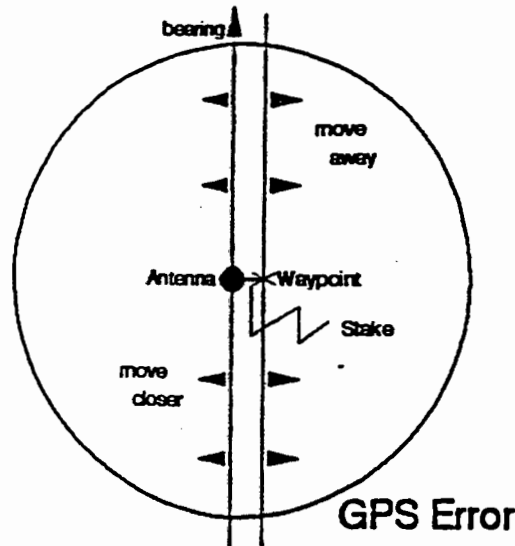


Figure D.3: GPS accuracy creates spurious results in measurement's compensation

D.2 Estimating Errors in the Measuring Technique

The mean error associated with the technique used to get a GPS representation of the way-point position in the dynamic tests, is explained in Figure D.4. The tagging of a measurement record to indicate the passing of a way-point will take place at the end of the 1s interval in which the way-point was passed. The way-point could therefore have been passed at the beginning or at the end of the 1s interval (sync. rate for this test). The post processing software took the average of the previous and the tagged record for an estimation of the GPS representation of the position of the way-point. On average therefore, the error due to the measuring technique in the direction of the bearing when passing the way-point, would be about a quarter of the distance moved in 1s travelling at a typical speed (or 2.5m whilst travelling at an average speed of 36km/h). This is a reasonable estimate. The average distance of the point of the stake from the way-point was estimated to be about .25m in the dynamic field tests and perhaps even less in the road dynamic tests. If on average, the way-point was passed half way through the 1s interval, then an estimate of a change in distance away or towards the way-point (perpendicular to the bearing) due to vehicle turning, could be anywhere between say 0 and .5m or an average of .25m. There would be even less turning in the road dynamic tests. There was also an estimated surveying error of half a metre in the gauss conform system, but as we are trying to estimate *average*

error, we will assume that the way-point was correctly surveyed. A typical mean measuring error can therefore be estimated to be 2.51m.

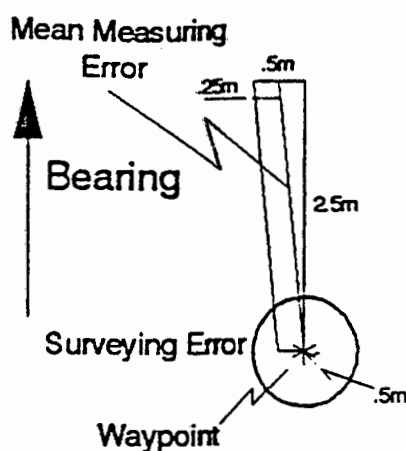


Figure D.4: Measurement technique error

The accuracy of surveyed heights however, decreases the further inland you go when surveying off the trig beacons. The surveying accuracies of the heights could be estimated to be at about 1m in this area in consideration of the surveying techniques employed. Again this is not significant when *average* errors are being calculated. In addition, the transformation error in converting the readings obtained from the GPS, is estimated at about a millimetre in x and y but at about 2cm in z. The latter is due to the fact that the further you are from the reference station (where the 2 vertical datums are taken as co-incident) the more the effects of the non-parallel vertical datums are felt (2km away from the reference station, a 2cm error in the XFORM transformation could be expected). These effects are not significant in this particular application. It is also true that the GPS makes poorer height measurements than lat. long. measurements and it is therefore expected that the 3D estimations of σ will be worse than the 2D estimations. No excuses will be made for the GPS system for 3D position determination, in terms of the errors introduced by the measuring technique when it comes to height errors. This is because the relief is not that variant over a 1s interval.

The conclusion is therefore that 2.51m will be taken off the 2D and 3D σ calculations for the field dynamic tests and the 3D σ value will be taken as being indicative of how the GPS is downgraded in accuracy in its attempt to calculate height measurements.

Another factor which needed to be taken into consideration was the synchronization of the GPS 1s interval with that of the interval at which the computer checks

for a tagging request of the next record received. This consideration is expressed in Figure D.5. With the receiver sending a measurement record at the 'sync.' rate, the computer is still in its previous 'tagging' cycle until the full record is received and the condition of a keyboard hit (kbhit) is tested (see the test software in Appendix G.1). The computer received every record every second on flushing the ring buffer, indicating that it must have been waiting for the next measurement despite the intermediary processing. The result of the software delay was that the condition for a tag request was only tested a certain delay time after the measurement was made valid by the GPS receiver. The danger of this is that if the keyboard was hit for a tagging request of the next record, at any time between the begin of the 1s interval of the GPS receiver and the time at which the keyboard buffer is checked, the previous record will be tagged instead of the one that becomes valid at the end of current 1s interval. As this delay is dictated by the speed of the serial link (at 33MHz, there are 27000 clock cycles for each bit period for the interrupt handler's write), the delay for the 100 characters of the record to be written to a 'C' structure would be .083s. This means that the above phenomenon would occur only 8.3% of the time. For this reason, this error of the measuring technique will be ignored.

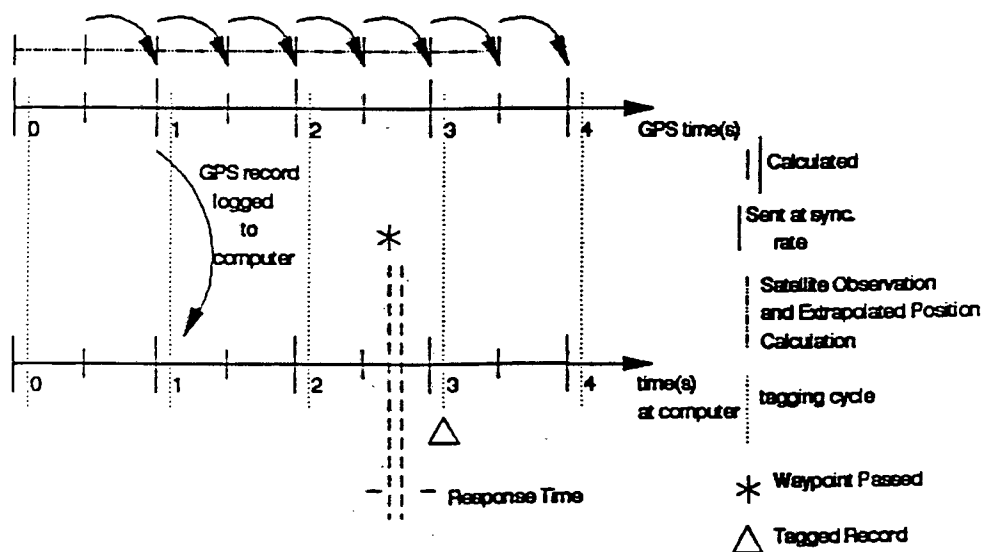


Figure D.5: Timing errors add to the measurement technique's errors

In retrospect, the software would have done better with setting a temporary variable by clearing the keyboard buffer immediately the start character of the record was received. The 'tagging' cycle of the computer would then only have been delayed by the time taken to send a single char down the serial line and for the interrupt handler to place it in the ring buffer (at 9600 baud the delay would be = .08% of the 1s interval).

Similarly a slow response time in passing the way-point, could result in the next record being tagged instead of the one at the end of the current 1s interval. Looking at the data received during the tests, it appeared as though the tagged GPS record actually lagged the position of the way-point (according to the sequence of logged positions leading up to the way-point) most of the time and indicates that the errors associated with the GPS dynamic calculations exceed that of any response time errors. In fact a response delay will aid the accuracy of the GPS dynamic measurements according to this observation or assist to balance out the effect of any computer delay errors described in the previous paragraph.

D.3 Accuracy Estimation Technique

The calculation of the σ values for the dynamic tests was done in a different way to that of the static tests. The errors that entered into the σ equation were not taken according to the distance from the average of all the logged values, but from the difference between the logged position and the surveyed position. For the road dynamic tests, the data set comprised of all the readings taken with the stake attached to the left and right hand sides of the vehicle. The data was adjusted according to the compensation described above and the previous and tagged records were averaged before being used to make an error estimate.

The σ of the static data obtained during the dynamic tests, was calculated in a similar fashion except that uncompensated and only the tagged records were used and no measurement technique compensation was implemented.

Appendix E

Uninterpolated Soil Sampled Data

An intuitive representation of the soil sampled data, would be to plot the contours of the levels determined from a triangulation interpolation technique of the sampled data. Examples of these are given in Figures E.1 and E.2. These representations are statistical and GIS outputs.

Another useful representation of the data is to plot it 3 dimensionally. As we are most interested in the phosphorous and potassium levels in the fertilizer business, Figures E.3 and E.4 represent the respective levels in 3 dimensions at the sample site positions. This form of representation gives a much better indication of the degree of variation and ‘trouble spots’. Implementing such a feature of GIS has the advantage of being able to tell at a glance whether spatially variable application is justified or not, according to some of the criteria expressed in Section 3.1.1.

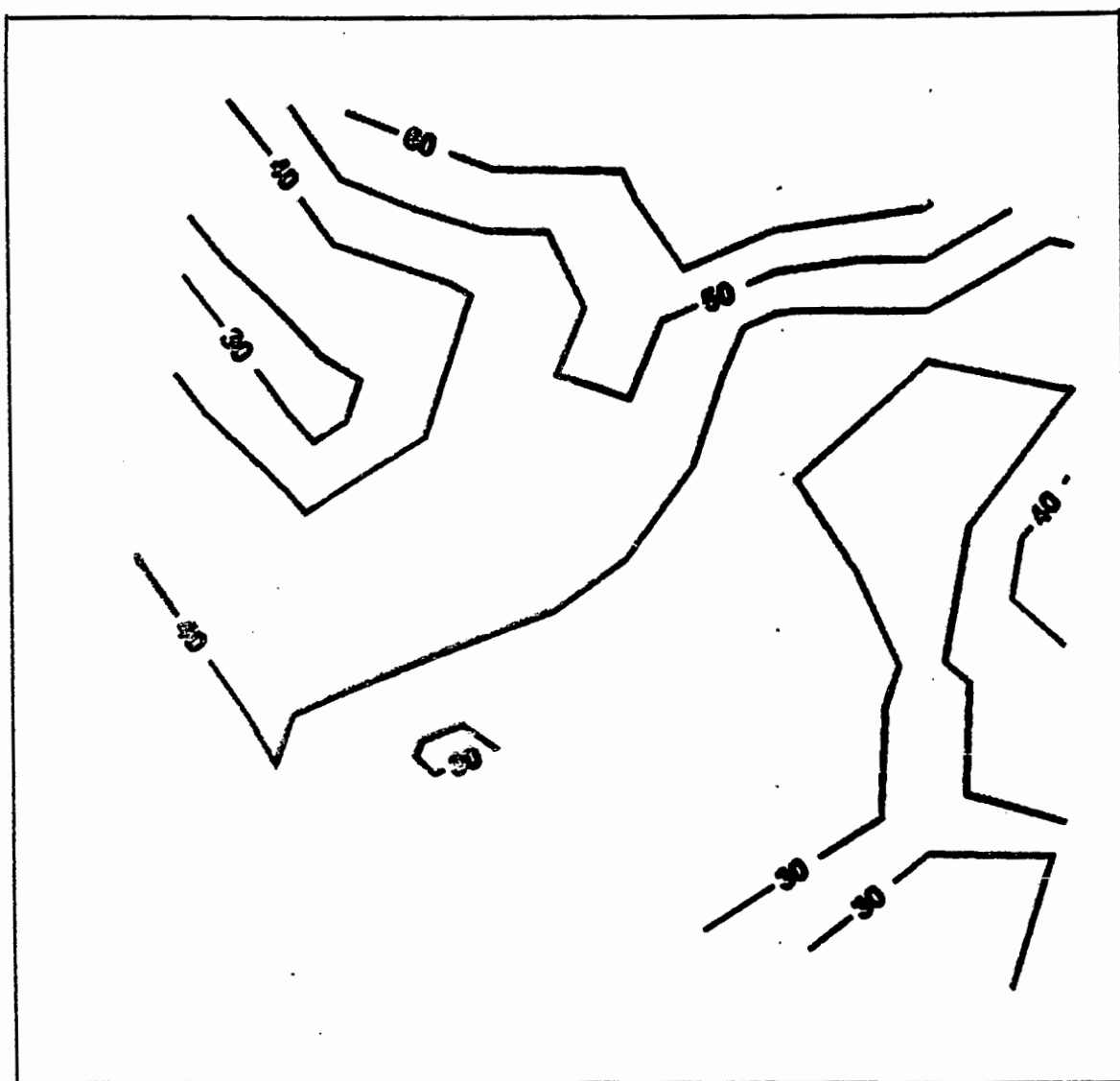


Figure E.1: The contours of P levels of the sampled data

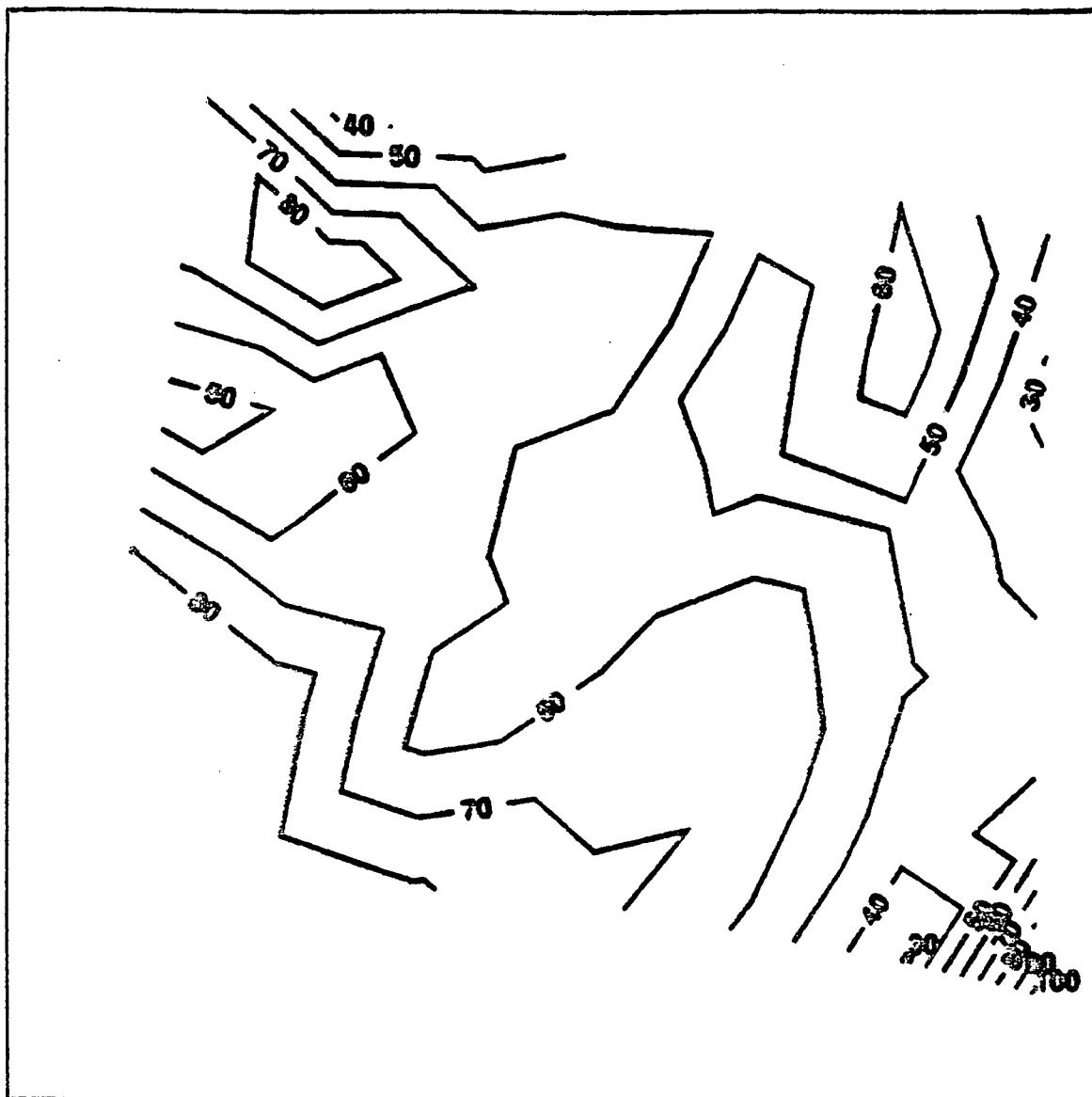


Figure E.2: The contours of K levels of the sampled data

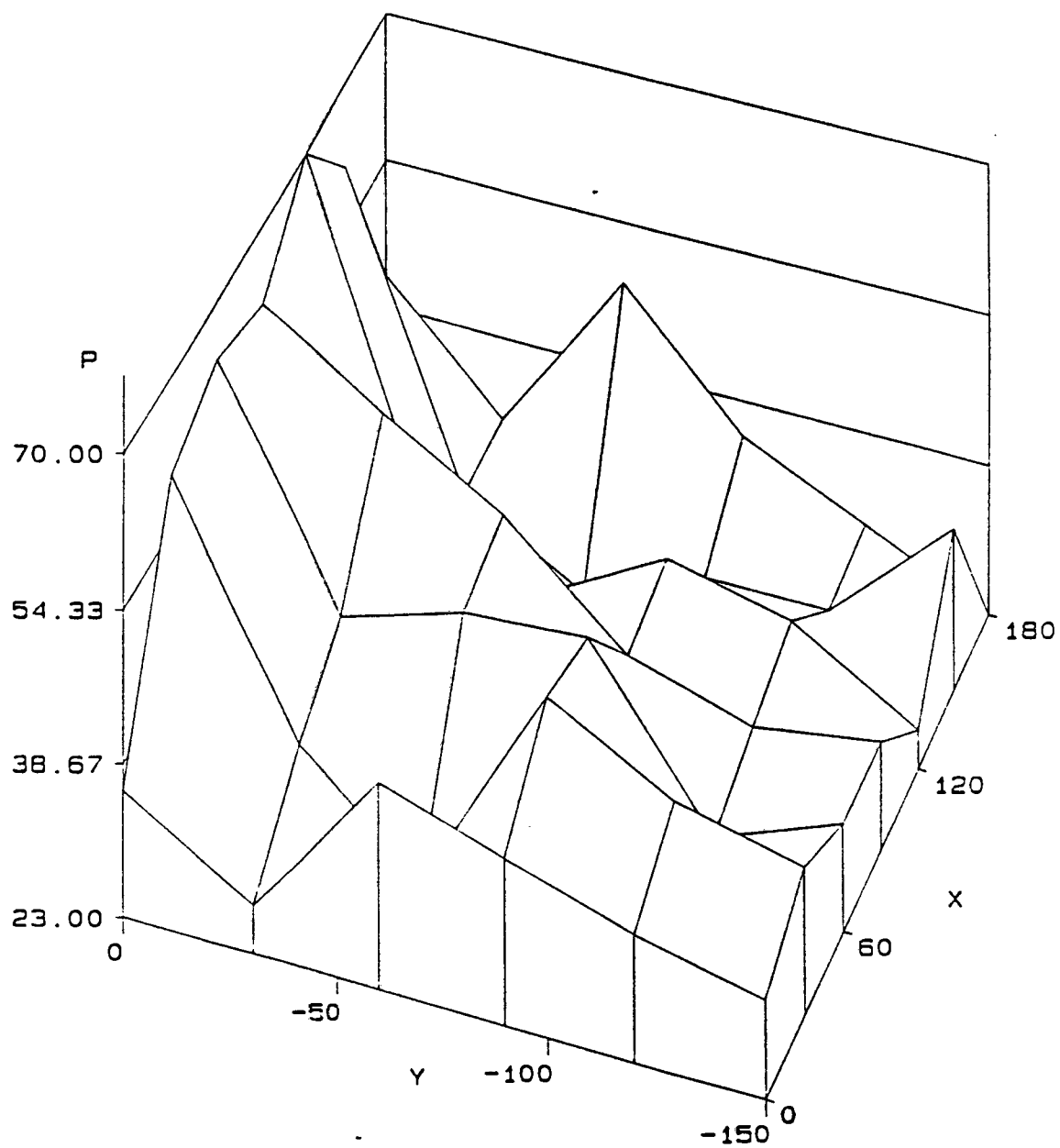


Figure E.3: Three dimensional plots of P levels at sample site positions

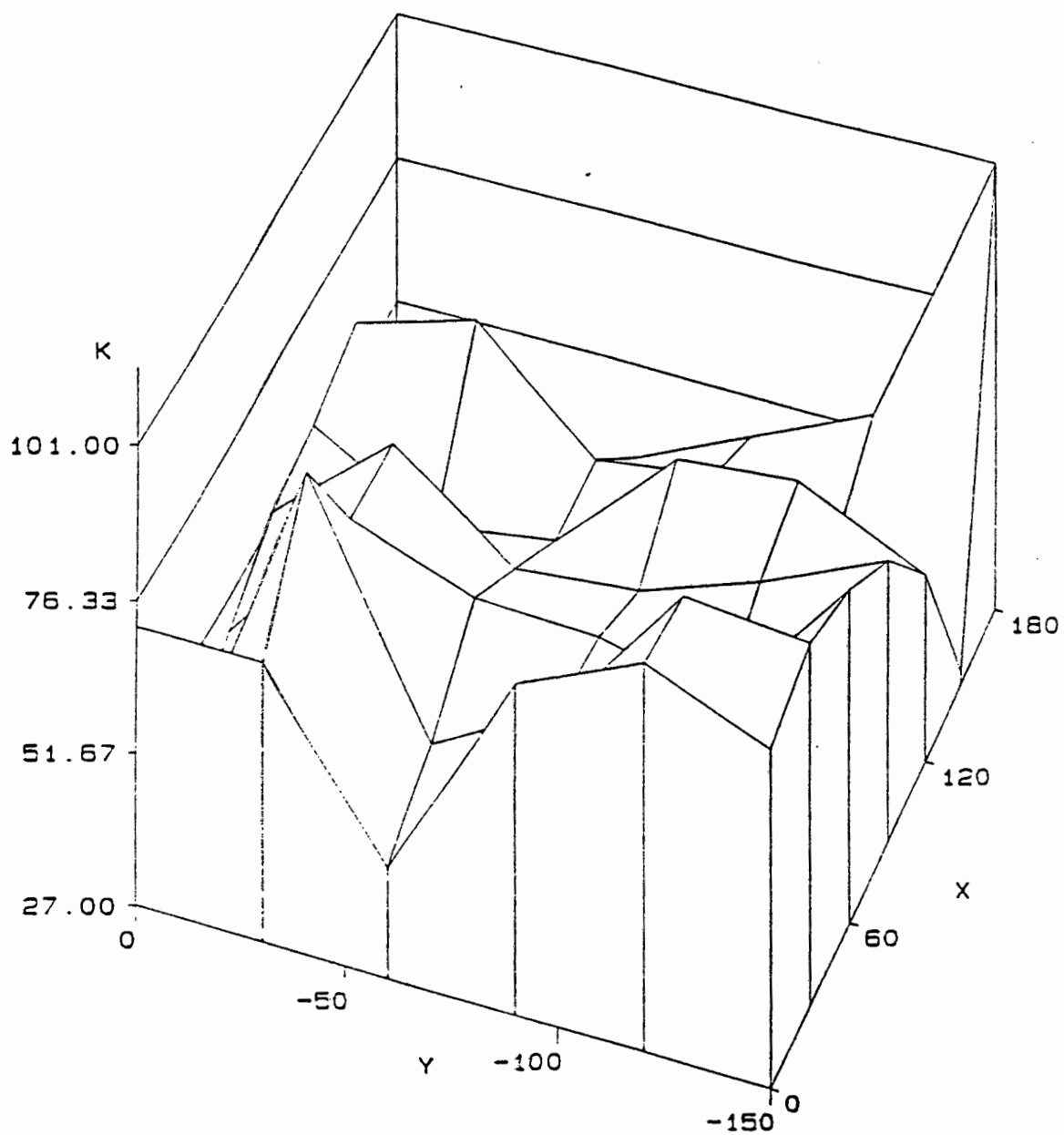


Figure E.4: Three dimensional plots of K levels at sample site positions

Appendix F

Summarized Kriging Theory

The semivariogram function is calculated according to the following:

$$\gamma(h) = \left[\frac{1}{2n(h)} \right] \sum_{i=1}^{n(h)} [Z(x_i) - Z(x_{i+h})]^2 \quad (\text{F.1})$$

Where

$n(h)$ = the number of samples separated by a distance of h .

$Z(x_i)$ = the value of the measured property at location x_i .

$Z(x_{i+h})$ = the value of the measured property at the location x_{i+h} .

Best fit curves to the semivariogram data can be calculated according to:

The linear model:

$$\begin{array}{llll} \gamma(h) & = & C_0 + Bh & \text{for} & 0 \leq h \leq a \\ \gamma(h) & = & C_0 + C_1 & \text{for} & h > a \end{array} \quad (\text{F.2})$$

The exponential model:

$$\gamma(h) = C_0 + C_1 \left[1 - \exp\left(\frac{-h}{a_0}\right) \right] \quad (\text{F.3})$$

Where

h = separation distance between samples.

a = a model parameter known as the range.

$(C_0 + C_1)$ = a model parameter known as the sill.

C_0 = a model parameter known as the nugget.

It was said that the sill was the total sample variance. In trying to find an estimate of this variable, the fact that the sill represents the total sample variance is in agreement with the result of a partial differentiation of the semivariance function with respect to C_1 in the linear model.

The Kriging equations are:

$$Z^*(x_0) = \sum_{i=1}^{N(x_0)} \lambda_i Z(x_i) \quad (\text{F.4})$$

where

x_0 = a location where no samples were collected.

$N(x_0)$ = the number of neighbouring measured data points used in the interpolation scheme.

λ_i = a weighted factor for the measured data that is yet to be determined.

$Z(x_i)$ = the measured data at location x_i .

The equations for determining the weights of the above function are:

$$\sum_{j=1}^{N(x_0)} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0) \quad \text{for} \quad i = 1 \text{ to } N(x_0) \quad (\text{F.5})$$

$$\sum_{j=1}^{N(x_0)} \lambda_j = 1$$

where

$\gamma(x_i, x_j)$ = value of the semivariogram model corresponding to the distance between two neighbouring observations at locations x_i and x_j .

$\gamma(x_i, x_0)$ = value of the semivariogram model corresponding to the distance between a measured observations at location x_i and an interpolated point at location x_0 .

μ = an unknown constant known as the lagrangian undetermined multiplier.

Appendix G

Software

The software listings in this appendix are included for the sponsor's benefit. As this project has a commercial application, the listings are given for the sake of completeness only. The coding has been commented to explain how the programs operate. The software listings are in the order that the calling programs declare the functions.

G.1 Field Test Software

The project file FTESTP.PRJ is such that on running it, it will bring up the menu to begin any one of the various tests that were carried out in the field.

The logged data was not provided as it would be about eight stiffy disks worth.

The following software printouts are all the programs in the FTESTP.PRJ project file.


```

/* This program is designed for the co-ordination of the tests of the */
/* GPS equipment and the implementation of the sampling phase of the */
/* spatially variable fertilizer applicator project.

#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <graphics.h>
#include "comm.h"
#include "condes.h"

/* Program header file. */
/* Async serial port library header */
/* file. */

extern int setupscreen(void);
extern int AllocRingBuffer(ASYNC *, int, int, int);
extern int setupst(ASYNC *);
extern int setup(ASYNC *);
extern int setup(ASYNC *);
extern int difflnk(ASYNC *);
extern int recvr(ASYNC *);
extern int statst(ASYNC *);
extern int dyntst(ASYNC *);
extern int samtst(ASYNC *);

int main(void)
{
    ASYNC port;
    int rcode;
    int xpos, ypos; /* For graphical positioning. */
    char choice;

    setupscreen(); /* Using graphics screen because no time */
                  /* limitations with interrupt driven data */
                  /* access from serial ports. */

    AllocRingBuffer(&port, RBUFSIZE, TBUFSIZE, FHEMFLG);

    /* The following code sets up the required interrupt handler and */
    /* initiates it as well as checks for the successful allocation of a */
    /* ring buffer for the serial data. */

    rcode = async_open(&port, COM1, COMINFO); /* Async Lib fn. */
    if (rcode != R_OK) /* rcode = RNONE if alloc buffer failed. */
    {
        printf("Async_open failed, exit code = %d\n", rcode); /* Errors to */
        printf("press any key to halt."); /* text screen. */
        getch(); /* Nice way to let you pass to end a non recurring process. */
        exit(rcode);
    } /* O.K. to exit because serial not open (hidden code) */

    /* Set up the screen menu options for the test required. */
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("press the number associated with the test desired.");
    ypos += 20;
    xpos += 50;
    moveto(xpos, ypos);
    outtext("0. Record a copy of the setup report.");
    ypos += 20;

```

```

    moveto(xpos, ypos);
    outtext("1. Display an updated record of GPS data for setup evaluation.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("2. Differential link testing.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("3. Receiver tests.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("4. Static tests.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("5. Dynamic tests.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("6. Sampling Tests.");
    /* Call the selected function. */
    choice = getch();

    switch (choice)
    {
        case '0': setupst(&port);
                    break;
        case '1': setup(&port);
                    break;
        case '2': difflnk(&port);
                    break;
        case '3': recvr(&port);
                    break;
        case '4': statst(&port);
                    break;
        case '5': dyntst(&port);
                    break;
        case '6': samtst(&port);
                    break;
        default : break;
    }

    closegraph();
    async_close(&port);
    return 0;
}

```

```
/* This function sets up the graphics screen. */

#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>

int setupscreen(void)
{
    /* Request auto detection. */
    int gdriver = DETECT, gmode, errorcode;

    /* Initialize graphics and local variables. */
    initgraph(&gdriver, &gmode, "");

    /* Read result of initialization. */
    errorcode = graphresult();
    /* If an error occurred, print to screen. */
    if (errorcode != grOk)
    {
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt:");
        getch(); /* Nice way to let you pass to end a non recurring process. */
        exit(1); /* Terminate with an error code. */
    } /* O.K. to exit because serial not yet open (hidden code). */

    cleardevice();
    settextstyle(SMALL_FONT, HORIZ_DIR, 0);
    setusercharsize(7, 8, 5, 4);
    settextjustify(LEFT_TEXT, CENTER_TEXT);

    return 0;
}
```

```

/* This file pre-initializes and allocates memory for the ring buffer */
/* required by the asynch_open function.

#if defined(__TURBOC__)
#include <alloc.h>
#define _fmalloc farmalloc
#else
#include <malloc.h>
#endif
#include "comm.h"

int AllocRingBuffer(
    ASYNC *port,
    int rxsize,
    int txsize,
    int useARMem)
{
    unsigned long memptr;
    int memsize;

    memsize = rxsize + txsize;

    if (useARMem || sizeof(char) == 4) /* if FAR Ring bufs */
        memptr = (unsigned long)_fmalloc(memsize);
    else /* if Ring buffers use NEAR memory */
        memptr = (unsigned long)(unsigned int)malloc(memsize);

    /* pre-initialize 4 required structure members */
    port->RxSize = rxsize; /* receive buffer size */
    /* port-> same as (*port). */
    port->TxSize = txsize; /* transmit buffer size */
    port->RingSeg = (int)(memptr >> 16); /* SEG adr */
    port->RingOfst = (int)memptr; /* OFST address */
    if (memptr == 0L) /* return 0 if no memory available */
        return 0; /* return 1, had some memory */
    return 1;
}

```

```

/* This function is used to write the setup record to a file. */
/* The setup report is sent to the serial port everytime the */
/* position calculation mode of cyclic reports is activated or */
/* whenever the single shot report of the setup is initiated. */

#include <conio.h>
#include "comm.h"
#include "stdio.h"
#include "comdes.h"
#include "graphics.h"

int setupst(ASYNC *aport)
{
    int xpos, ypos; /* only used for prompting. */
    char control = 'n';
    int rxch; /* a received character and status byte from the ring buffer. */
    char mesg = 'n'; /* the character written to the file. */
    FILE *fp;

    /* setup the prompt on the graphics screen */
    clrdevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Press a key to begin; provided the GPS instrument");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("has the position calc mode switched off.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Then turn the position calc mode on to allow setup logging.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note : 'q' will terminate this session.");

    getch();
    /* open the report file to log the setup report */
    if((fp = fopen("setupst", "wt")) == NULL)
    {
        clrdevice();
        printf("Can't open %s.\n", "setupst");
        printf("Press any key to quit.");
        getch();
        control = 'q';
    }

    /* clear the ring buffer */
    async_rxflush(aport);

    /* If the report file opened correctly and a key other than 'q' */
    /* is pressed, then start logging data from the serial input to */
    /* the file until 'q' is pressed. */
    while ((control != 'q') && (control != 'Q'))
    {
        if (kbhit())
            control = getch();

        /* Receive a character from the ring buffer if it exists */
        if ((rxch = async_rx(aport)) & B_RXEMPTY)

```

```

{
    mesg = (rxch & 0xff);
    /* a port here is an address. */
    /* Don't change mesg if empty */
    /* buffer. */

    putc(mesg, fp);
}

return 0;
}

```

```

/* This program reads data transmitted from a GPS receiver at a set baud */
/* every second or so. This is done by interrupts and writing */
/* the data to a ring buffer. Finally the graphics screen is used to */
/* display the data.

#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <graphics.h>
#include "comm.h"
#include "comdes.h"

extern int respond (ASYNC *, char);

int setup(ASYNC *aport)
{
    char control = 'b';
    int xpos, ypos; /* position on graphics screen */

    /* provide prompt */
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    cleardevice();
    moveto(xpos, ypos);
    outtext("Press any key for an updated version of input (NB have serial data co
nected).");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note: 'q' will terminate this session.");

    /* as long as keypressed is not 'q', respond to */
    /* it by updating the screen with a refreshed version */
    /* of the GPS cyclic report. */
    while ((control != 'q') && (control != 'Q'))
    {
        while(!kbhit())
            continue;
        control = getch();
        respond(aport, control);
    }

    return 0;
}

```

```

/* This function is used to update an indication of the state of */
/* the differential link and provide an option to record the */
/* position with the differential link info.
#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include "comm.h"
#include "comdes.h"

extern int recmeas(FILE *, GPSREC *);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);

int diffLink(ASYNC *aport)
{
    int xpos, ypos;
    FILE *fp;
    GPSREC info;
    char control = 'b';

    /* data logged to file */
    /* struct of GPS parameters */

    /* set up graphics prompting screen */
    clrdevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Strike any key for a single measurement to be recorded.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note: 'q' will terminate this session.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("The differential link is:");

    /* set graphics display screen */
    setfillstyle(SOLID_FILL, EGA_RED);
    bar(getmaxx()/4, getmaxx()/4, getmaxx()*3/4, getmaxx()*3/4);
    setviewport(getmaxx()/4, getmaxx()/4, getmaxx()*5/4, getmaxx()*3/4, 1);
    settextstyle(DEFAULT_FONT, HORIZ_DIR, 4);
    bar(0, 0, getmaxx()/2, getmaxx()/2);
    outtextxy(getmaxx()/12, getmaxx()/5, "WAITING");

    /* open input file and goto begin */
    if((fp = fopen("diffst", "w")) == NULL)
    {
        printf("Can't open %s.\n", "diffst");
        printf("Press any key to quit.");
        getch();
        return 1;
    }
    fseek(fp, 0L, SEEK_SET);

    /* continue for as long as 'q' isn't pressed */
    while((control != 'q') && (control != 'Q'))
    {
        int noser = 0; /* an indication if no serial data is being received */
        find_meas(aport, &noser); /* Finds the begin of a sync time */
        /* measurement (not the begin of a cyclic */
        /* report) and passes an indication if */
        /* serial data exists. */
        /* If there is serial data then read in a measurement from the */
        /* beginning of it and assign it to the GPS structure. */
        /* Update display according to the differential correc. field of */
        /* struct. */
        if(noser == 0)
        {
            assign_to_struct(&info, aport);

            if ((info.diff == 'd'))
            {
                bar(0, 0, getmaxx()/2, getmaxx()/2);
                outtextxy(getmaxx()/12, getmaxx()/5, "WORKING");
            }
            if ((info.diff != 'd'))
            {
                bar(0, 0, getmaxx()/2, getmaxx()/2);
                outtextxy(getmaxx()/12, getmaxx()/5, "DOWN");
            }
        }
        /* If there is no serial data : display a message */
        if (noser == 1)
        {
            bar(0, 0, getmaxx()/2, getmaxx()/2);
            outtextxy(getmaxx()/12, getmaxx()/5, "WAITING");
        }
        /* If the keyboard is pressed; log the struct contents to a file. */
        /* If there is no serial data and a log is requested; */
        if(kbhit())
        {
            if (((control = getch()) != 'q') && (control != 'Q') && (noser == 0))
            else
            {
                recmeas(fp, &info);
                if ((noser == 1) && (control != 'q') && (control != 'Q'))
                {
                    clrdevice();
                    printf("No serial data Press a key to quit.");
                    getch();
                    break;
                }
            }
        }
        /* close file and end */
        fclose(fp);
        return 0;
    }
}

```

```

/* This function is used to update an indication of the state of */
/* the differential link and provide an option to record the */
/* position with the differential link info.
#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include "comm.h"
#include "comdes.h"

extern int recmeas(FILE *, GPSREC *);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);

int diffLink(ASYNC *aport)
{
    int xpos, ypos;
    FILE *fp;
    GPSREC info;
    char control = 'b';

    /* data logged to file */
    /* struct of GPS parameters */

    /* set up graphics prompting screen */
    clrdevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Strike any key for a single measurement to be recorded.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note: 'q' will terminate this session.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("The differential link is:");

    /* set graphics display screen */
    setfillstyle(SOLID_FILL, EGA_RED);
    bar(getmaxx()/4, getmaxx()/4, getmaxx()*3/4, getmaxx()*3/4);
    setviewport(getmaxx()/4, getmaxx()/4, getmaxx()*5/4, getmaxx()*3/4, 1);
    settextstyle(DEFAULT_FONT, HORIZ_DIR, 4);
    bar(0, 0, getmaxx()/2, getmaxx()/2);
    outtextxy(getmaxx()/12, getmaxx()/5, "WAITING");

    /* open input file and goto begin */
    if((fp = fopen("diffst", "w")) == NULL)
    {
        printf("Can't open %s.\n", "diffst");
        printf("Press any key to quit.");
        getch();
        return 1;
    }
    fseek(fp, 0L, SEEK_SET);

    /* continue for as long as 'q' isn't pressed */
    while((control != 'q') && (control != 'Q'))
    {
        int noser = 0; /* an indication if no serial data is being received */
        find_meas(aport, &noser); /* Finds the begin of a sync time */
        /* measurement (not the begin of a cyclic */

```

```

/* This function module is meant for the graphical representation and */
/* logging of data taken in the receiver test to log the overshoot in */
/* the positioning data when the vehicle is brought to a sudden stop. */

#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include "comm.h"
#include "comdes.h"

extern int control_logging(char *, char *, const char *, const int, GPSREC *, int *);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);
extern int extract_posie(GPSREC *, float *, float *);
extern int getxy(float, float, int *, int *);

/* Graphics variables for graphical representation of lat and */
/* long positions. */
/* This is the No. of graphic points across the display screen */
int grph_pts;

float scale; /* This variable will be used to convert a */
/* measurement in geographical co-ordinates */
/* to a scaled xy graphic co-ordinate. */
int cntprtx, cntpty; /* screen points */
float cntrlat, cntrlng;

int recvr(ASYNC *aport)
{
    GPSREC info; /* GPS parameter structure */

    /* graphics variables */
    float blat, blng, elat, elng; /* for a stopping line */

    /* logging variables */
    int noser = 0; /* indicates if there is no serial data */
    char old = 'e';
    int xpos, ypos; /* also for control : contains old control char */
    int val = 110; /* only use xpos for logging and control not graphics */
    /* Initial value passed to control_logging so that no */
    /* special tags for logged records are invoked for this test. */
    char *base = "rectst"; /* report file name */

    /* graphics */
    float lat, lng;
    int oldx, oldy; /* old graphics positions */
    int x, y; /* current graphics positions */

    /* Set up screen for graphic representation, prompt for zoom size */
    clrdevice();
    printf("Enter the letter 'z', 'n' or 'o' for a zoomed, normal or \"
        \"distanced graphical representation of the data.\n");
    scanf("%c", &zoom);
    while(getchar() != '\n') /* NB! */
        continue;

    /* Log one end of the stopping line if there is serial data to log */
    printf("Goto one end of stopping point and press a key.\n");
    getch();

```

```

find_meas(aport, &noser); /* find the begin of a measurement */
if (noser == 0)
{
    assign_to_struct(&info, aport); /* Assign the measurement */
    /* parameters to the struct. */
    extract_posie(&info, &blat, &blng); /* Extract the position */
    /* string to a float. */
    printf("Beginstop : %f %f \n", blat, blng);
}

/* Repeat for the other end */
printf("Goto the other end of stopping point and press a key.\n");
getch();
find_meas(aport, &noser);
if (noser == 0)
{
    assign_to_struct(&info, aport);
    extract_posie(&info, &elat, &elng);
    printf("Endstop : %f %f \n", elat, elng);
}

getch();

/* Set up graphics screen for control and position representations */
clrdevice();
xpos = getmaxx() / 10;
ypos = getmaxy() / 10;
moveto(xpos, ypos);
outtext("Press 'b' to begin logging data and 'e' to stop.");
ypos += 20;
moveto(xpos, ypos);
outtext("Note : 'q' will terminate this session.");

/* sub-screen for graphical display */
setviewport(xpos, ypos + 30, getmaxx(), getmaxy(), 1);
setfillstyle(SOLID_FILL, EGA_BLUE);
grph_pts = getmaxy() - (ypos + 30);
bar3d(0, 0, grph_pts, grph_pts, 0, 0);
setfillstyle(SOLID_FILL, EGA_BLACK);

/* prepare for graphic drawing */
switch (zoom)
{
    case 'z': scale = 0.054545; /* up to 6 or 7 sig fig */
        /* half screen = approx 100m */
        break;
    case 'n': scale = 0.218181; /* 400m */
        break;
    case 'o': scale = 0.436363; /* 800m */
        break;
    default : break;
}

cntprtx = grph_pts/2;
cntpty = grph_pts/2;

cntrlat = 0.0;
cntrlng = 0.0;

/* Loop continuously, logging (if requested) and displaying positions */

```

```

while((control != 'q') && (control != 'Q'))
{
    noser = 0;
    find_meas(aport, &noser); /* find the begin of a measurement */

    /* If there is serial data then assign it to the info structure */
    if(noser == 0)
        assign_to_struct(&info, aport);

    /* update loop control if key has been pressed */
    if (kbhit())
    {
        old = control;
        control = getch();
    }

    /* Use the character pressed to control when to begin */
    /* and end logging to a file. */
    control_logging(&old, &control, base, noser, &info, &val);

    /* If differential corrections parameter exists, represent */
    /* it graphically or delete the representation. */
    if (info.diff == 'd')
    {
        moveto(grph_pts + 10, 10);
        settextstyle(SMALL_FONT, HORIZ_DIR, 6);
        outtext("D");
        settextstyle(SMALL_FONT, HORIZ_DIR, 4);
    }
    else
    {
        bar(grph_pts + 5, 0, grph_pts + 20, 40);
    }

    /* Graphics section */
    /* If there is serial data, use the structure info graphically */
    if ((noser == 0) && (control == 'b') && (old == 'b'))
    {
        extract_posie(&info, &lat, &lng); /* Extract the position */
        /* string to a float. */

        /* If this is the first position received : centre the graph */
        /* Also draw the stopping line */
        if (cntrlat == 0.0)
        {
            /* clear the graphics screen */
            setfillstyle(SOLID_FILL, EGA_BLUE);
            bar3d(0, 0, grph_pts, grph_pts, 0, 0);
            setfillstyle(SOLID_FILL, EGA_BLACK);

            /* initialize centre position */
            /* put the first measurement at screen centre */
            cntrlat = lat;
            cntrlng = lng;

```

```

        oldx = cntrptx;
        oldy = cntrpty;

        /* Convert the beginning and end points to */
        /* graphic points and draw the stopping line. */
        setcolor(EGA_RED);
        getxy(&lat, &lng, &y, &x);
        moveto(x, y);
        getxy(&elat, &elng, &y, &x);
        lineto(x, y);
        setcolor(EGA_WHITE);
    }

    /* Else use the new position to plot a point */
    /* and draw a line from the old position. */
    else
    {
        getxy(&lat, &lng, &y, &x);

        /* move to old x and y if bar or outtext changes CP */
        moveto(&oldx, &oldy);
        lineto(x, y);
        oldx = x;
        oldy = y;
    }
}

return 0;
}

```



```

/* This function is for the logging and graphical representation of */
/* the gps data for the static tests */

#include <graphics.h>
#include <conio.h>
#include "comm.h"
#include "comdes.h"

extern int control_logging(char *, char *, const char *, const int, GPSREC *, int
*);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);
extern int extract_posie(GPSREC *, float *, float *);
extern int getxy(const float, const float, int *, int *);

/* global variables required for graphics */
extern int grph_pts;
extern float scale;
extern int cntprtx, cntprty; /* screen points */
extern float cntrlat, cntrlng;

int statstst(ASYNC *aport)
{
    GPSREC info;
    /* variables for the control of data logging */
    char control = 'e';
    char old = 'x';
    int xpos, ypos; /* only use xpos for graphics indicating
    logging and control */

    int val = 110; /* set tagging info. out of the range
    of any meaningful tagging values */

    /* provide instructions on screen */
    cleardevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("press 'b' to begin logging data and 'e' to stop.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note : 'q' will terminate this session.");

    /* set up section of the screen for graphic picture of logged points */
    setviewport(xpos, ypos + 30, getmaxx(), getmaxy(), 1);
    setfillstyle(SOLID_FILL, EGA_BLUE);
    grph_pts = getmaxx() - (ypos + 30);
    bar3d(0, 0, grph_pts, grph_pts, 0, 0);
    setfillstyle(SOLID_FILL, EGA_BLACK);

    /* change scale to suit application */
    scale = 0.054545; /* approx 1cm of 55cm of 3min at 1: 10000 is 100m */

    /* initialize variables for graphics */
    cntprtx = (int)grph_pts/2;
    cntprty = (int)grph_pts/2;

```

```

    cntrlat = 0.0;
    cntrlng = 0.0;

    while((control != 'q') && (control != 'Q'))
    {
        int noser = 0;
        char *base = "statstst"; /* file base name for static tests */

        /*graphics*/
        float lat, lng;
        int x, y;

        /* check the data from the serial port for the first character of a measure
        ment
        and test whether serial data is present */
        find_meas(aport, &noser);

        /* If there is serial data then assign it to the info structure */
        if(noser == 0)
            assign_to_struct(&info, aport);

        /* control data logging according to user requests */
        if (kbhit())
        {
            old = control;
            control = getch();
        }

        /* check the data from the serial port for the first character of a measure
        ment
        and test whether serial data is present */
        control_logging(&old, &control, base, noser, &info, &val);

        /* if the 'd' parameter of the record is set then indicate on screen
        else clear the indication */
        if (info.diff == 'd')
        {
            moveto(grph_pts + 10, 10);
            settextstyle(SMALL_FONT, HORIZ_DIR, 6);
            outtext("b");
            settextstyle(SMALL_FONT, HORIZ_DIR, 4);
        }
        else
        {
            /* took out moveto */
            bar(grph_pts + 5, 0, grph_pts + 20, 40);
        }

        /* Graphics section */

        /* If there is serial data, use the structure info graphically */
        if ((noser == 0) && (control == 'b') && (old == 'b'))
        {
            /* extract a latitude and longitude from the structure data
            from a string to a float */
            extract_posie(&info, &lat, &lng);

```

```

/* if this is the first position plot on the screen
   then put it at the centre else plot from the last point. */
if (cntrlat == 0.0)
{
    /* initialize centre position */
    /* put the first measurement at screen centre */
    setfillstyle(SOLID_FILL, EGA_BLUE);
    bar3d(0, 0, graph_pts, graph_pts, 0, 0);
    setfillstyle(SOLID_FILL, EGA_BLACK);
    cntrlat = lat; /* for subsequent line drawing from the
                    last point to the current point */
    cntrlng = lng;
}
else
{
    getxy(lat, lng, &y, &x);

    moveto(x, y);
    lineto(x, y);

    }
    }
    return 0;
}

```

```

/* This function is for the logging and graphical representation of */
/* the gps data in searching for areas of loss of LOS and MP. */
/* It will also allow potentially corrupted data by MP to be tagged */
/* and chosen positions to be tagged. */

#include <graphics.h>
#include <conio.h>
#include "comm.h"
#include "condes.h"

extern int control_logging(char *, char *, const char *, const int, GPSREC *, int
*);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);
extern int extract_posie(GPSREC *, float *, float *);
extern int getxy(const float, const float, int *, int *);

/* global variables required for graphics */
extern int grph_pts;
extern float scale;
extern int cntrptx, cntrpty; /* screen points */
extern float cntrlat, cntrlng;

int dyntst(ASYNC *aport)
{
    GPSREC info;
    /* variables for the control of data logging */
    char control = 'e';
    char old = 'x';
    int xpos, ypos; /* only use xpos for graphics indicating
    logging and control */
    char *base = "dyntst"; /* output file base name */
    int val = 110; /* set tagging info. out of the range
    of any meaningful tagging values */

    /*graphics*/
    float lat, lng;
    int oldx, oldy, x, y;

    /* provide instructions on screen */
    clrdevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("press 'b' to begin logging data and 'e' to stop.");
    ypos += 10;
    moveto(xpos, ypos);
    outtext("whilest logging, press enter to tag a measurement"
    "and spacebar to begin and end MP tagging");
    ypos += 10;
    moveto(xpos, ypos);
    outtext("Note : 'q' will terminate this session.");

    /* set up section of the screen for graphic picture of logged points */
    setviewport(xpos, ypos + 30, getmaxx(), getmaxy(), 1);
    setfillstyle(SOLID_FILL, EGA_BLUE);
    grph_pts = getmaxy() - (ypos + 30);
    bar3d(0, 0, grph_pts, grph_pts, 0, 0);
    setfillstyle(SOLID_FILL, EGA_BLACK);

```

```

/* change scale to suit application */
scale = 0.054545; /* approx 1cm of 55cm of 3min at 1: 10000 is 100m */

/* initialize variables for graphics */
cntrptx = (int)grph_pts/2;
cntrpty = (int)grph_pts/2;

cntrlat = 0.0;
cntrlng = 0.0;

while((control != 'q') && (control != 'Q'))
{
    int noser = 0;

    /* check the data from the serial port for the first character of a measure
    ment
    and test whether serial data is present */
    find_meas(aport, &noser);

    /* If there is serial data then assign it to the GPS info structure */
    if((noser == 0)
    assign_to_struct(&info, aport);

    /* alter the variables for the control of the logging and tagging of
    measurements */
    if (kbhit())
    {
        if ((val = getch()) == 'q' || (val == 'Q') || (val == 'b') || (val ==
        'e'))
        {
            old = control;
            control = val;
        }
    }

    /* log the records of the GPS structure according to the
    users request */
    control_logging(&old, &control, base, noser, &info, &val);

    /* if the 'd' parameter of the record is set then indicate on screen
    else clear the indication */
    if (info.diff == 'd')
    {
        moveto(grph_pts + 10, 10);
        settextstyle(SMALL_FONT, HORIZ_DIR, 6);
        outtext("D");
        settextstyle(SMALL_FONT, HORIZ_DIR, 4);
    }
    else
    {
        moveto(grph_pts + 10, 10);
        bar(grph_pts + 5, 0, grph_pts + 20, 40);
    }
}

```

```

    )
    /* Graphics section */
    /* If there is serial data, use the structure info graphically */
    if (noser == 0)
    {
        /* extract a latitude and longitude from the structure data
        from a string to a float */
        extract_posie(&info, &lat, &lng);

        /* if this is the first position plot on the screen
        then put it at the centre else plot from the last point. */
        if (cntrlat == 0.0)
        {
            /* initialize centre position */
            /* put the first measurement at screen centre */
            setfillstyle(SOLID_FILL, EGA_BLUE);
            bar3d(0, 0, grph_pts, grph_pts, 0, 0);
            setfillstyle(SOLID_FILL, EGA_BLACK);
            cntrlat = lat;
            cntrlng = lng;
            oldx = cntrptx; /* for subsequent line drawing from the
            last point to the current point */
            oldy = cntrpty;
        }
        else
        {
            getxy(lat, lng, &y, &x);

            /* moveto old x and y if 'bar' or 'outtext' above changes CP */
            moveto(oldx, oldy);
            lineto(x, y);
            oldx = x;
            oldy = y;
            /* if out of range of graphics screen recentre the plot */
            if ((abs(x - cntrptx) >= grph_pts/2) | (abs(y - cntrpty) >= grph_pts/
2))
            {
                cntrlat = 0.0;
            }
        }
    }
    return 0;
}

```

```

/* This function enables the labelling of soil samples and the
/* graphical representation of the positioning data at that point. */

#include <graphics.h>
#include <conio.h>
#include "comm.h"
#include "comdes.h"

extern int control_logging(char *, char *, const char *, const int, GPSREC *, int
*);
extern int assign_to_struct(GPSREC *, ASYNC *);
extern int find_meas(ASYNC *, int *);
extern int extract_posie(GPSREC *, float *, float *);
extern int getxy(const float, const float, int *, int *);

/* Global variables required for graphics */
extern int grph_pts;
extern float scale;
extern int cntprtx, cntprty; /* screen points */
extern float cntrlat, cntrlng;

int samtst(ASYNC *aport)
{
    GPSREC info;
    /* variables for the control of data logging */
    char control = 'e';
    char old = 'x';
    int xpos, ypos; /* only use xpos for graphics indicating
    logging and control */
    char *base = "samtst"; /* output file base name */
    int val = 110; /* set tagging info. out of the range
    of any meaningful tagging values */
    ct = 0;
    char str[30];

    /* graphics */
    float lat, lng;
    int x, y;

    /* provide instructions on screen */
    clrdevice();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Press 'b' to begin logging data and 'e' to stop.");
    ypos += 10;
    moveto(xpos, ypos);
    outtext("Note: 'q' will terminate this session.");

    /* set up section of the screen for graphic picture of logged points */
    setviewport(xpos, ypos + 30, getmaxx(), getmaxy(), 1);
    setfillstyle(SOLID_FILL, EGA_BLUE);
    grph_pts = getmaxy() - (ypos + 30);
    bar3d(0, 0, grph_pts, grph_pts, 0, 0);
    setfillstyle(SOLID_FILL, EGA_BLACK);

```

```

/* change scale to suit application */
scale = 0.054545; /* approx 1cm of 55cm of 3min at 1: 10000 is 100m */

/* initialize variables for graphics */
cntprtx = (int)grph_pts/2;
cntprty = (int)grph_pts/2;

cntrlat = 0.0;
cntrlng = 0.0;

while((control != 'q') && (control != 'Q'))
{
    int noser = 0;

    /* check the data from the serial port for the first character of a measure
    and test whether serial data is present */
    find_meas(aport, &noser);

    /* If there is serial data then assign it to the GPS info structure */
    if(noser == 0)
        assign_to_struct(&info, aport);

    /* alter the variables for the control of the logging and tagging of
    measurements */
    if (kbhit())
    {
        old = control;
        control = getch();

        /* if there is another request whilst logging then tag the data
        with the sample no. */
        if ((control == 'b') && (old != 'b'))
            val = 40 + ++ct; /* give the sample no. an offset so that the
            logging function will not confuse it with
            other tagging info used by other functions */

        /* log the records of the GPS structure according to the
        users request */
        control_logging(&old, &control, base, noser, &info, &val);

        /* if the 'd' parameter of the record is set then indicate on screen
        else clear the indication */
        if (info.diff == 'd')
        {
            moveto(grph_pts + 10, 10);
            settextstyle(SMALL_FONT, HORIZ_DIR, 6);
            outtext("d");
            settextstyle(SMALL_FONT, HORIZ_DIR, 4);
        }
        else
        {
            bar(grph_pts + 5, 0, grph_pts + 20, 40);

```

```

)
/* if data is being logged, indicate which sample
   else clear the indication */
if (control == 'b')
(
    moveto(grph_pts + 10, 50);
    settextstyle(SMALL_FONT, HORIZ_DIR, 5);
    sprintf(str, "Logging Sample no. : %d", ct);
    outtext(str);
    settextstyle(SMALL_FONT, HORIZ_DIR, 4);
)
else
(
    bar(grph_pts + 5, 40, grph_pts + 200, 60);
)
/* Graphics section */
/* If there is serial data, use the structure info graphically */
if ((noser == 0) && (control == 'b') && (old == 'b'))
(
    /* extract a latitude and longitude from the structure data
       from a string to a float */
    extract_poste(&info, &lat, &lng);

    /* if this is the first position plot on the screen
       then put it at the centre else plot from the last point. */
    if (cntrlat == 0.0)
    (
        /* initialize centre position */
        /* put the first measurement at screen centre */
        setfillstyle(SOLID_FILL, EGA_BLUE);
        bar3d(0, 0, grph_pts, grph_pts, 0, 0);
        setfillstyle(SOLID_FILL, EGA_BLACK);
        cntrlat = lat;
        cntrlng = lng;
    )
    else
    (
        getxy(&lat, &lng, &x);

        /* moveto x and y if 'bar' or 'outtext' above changes CP */
        moveto(x, y);
        lineto(x, y);

        /* if out of range of graphics screen recentre the plot */
        if ((abs(x - cntrptx) >= grph_pts/2) | (abs(y - cntrpty) >= grph_pts/
2))
            cntrlat = 0.0;
    )

```

```

)
    return 0;
)
,

```

```

/* Respond to an 'update of info from GPS' request */
/* by outputting the contents of a cyclic report to the screen. */

#include <conio.h>
#include <graphics.h>
#include <string.h>
#include "comm.h"

extern int sbegin(ASYNC *, char *);

int respond(ASYNC *aport, char cntrl)
{
    int xpos, ypos;          /* The received character and status */
    int rxch;                /* byte from the ring buffer. */
    char msg = 'n';          /* initialize character to be written to the screen */

    /* If the control character sent is not 'q', then write a report */
    /* to the screen */
    if ((cntrl != 'q') && (cntrl != 'Q'))
    {
        cleardevice();
        xpos = getmaxx() / 40;
        ypos = getmaxy() / 20;
        moveto(xpos, ypos);

        /* find the beginning of the cyclic report */
        sbegin(aport, &msg);

        /* output the characters of the report row by row to the screen */
        do
        {
            int index = 0;    /* index to the string array */
            char str[135];    /* if not initializing must assign space */

            strcpy(str, "");
            str[index++] = msg;
            do
            {
                do
                {
                    rxch = async_rx(aport);
                } while ((rxch & B_REMPTY)); /* Only pass if received a */
                /* char from unempty buffer. */

                msg = rxch & 0xff;
                str[index++] = msg;
            } while (msg != '\n');
            str[index] = '\0';

            outtext(str);
            ypos += 20;        /* move to the next line */
            moveto(xpos, ypos);
            do
            {
                rxch = async_rx(aport);
            } while ((rxch & B_REMPTY)); /* Only pass if received a */
                /* char from unempty buffer. */

```

```

        } while ((msg = (rxch & 0xff)) != ' '); /* The end of a report */
        /* ends with a space after the newline */
        /* which can be omitted from the viewed */
        /* report. */
    }

    return 0;
}

```

```

/* This function writes selected parts of a measurement written in the */
/* GPS structure into the chosen */
/* file. */

```

```

#include <stdio.h>
#include "comdes.h"

```

```

int recmeas(FILE *fp, GPSREC *ainfo)
{

```

```

    fputs(ainfo->tim, fp);
    putc(' ', fp);

```

```

    /* indicate whether diff link parameter exists */
    if (ainfo->diff == 'd')

```

```

        putc(ainfo->diff, fp);
    else
        putc('n', fp);

```

```

    putc(' ', fp);
    fputs(ainfo->lat, fp);
    putc(' ', fp);
    fputs(ainfo->lng, fp);
    putc(' ', fp);
    fputs(ainfo->hgt, fp);
    putc(' ', fp);
    fputs(ainfo->pdp, fp);
    putc(' ', fp);
    fputs(ainfo->vvel, fp);
    putc(' ', fp);
    fputs(ainfo->hvel, fp);
    putc(' ', fp);
    fputs(ainfo->hdg, fp);
    putc(' ', fp);
    fputs(ainfo->sat, fp);
    putc(' ', fp);
    putc('n', fp);
    putc('\n', fp);

```

```

    /* no tagging of the record in any way */

```

```

    return 0;
}

```



```

/* This function reads the information in the buffer and assigns it to */
/* a structure as a more elegant and semi permanent data form. */

#include <stdio.h>
#include "comm.h"
#include "comdes.h"

int assign_to_struct(GPSREC *ainfo, ASYNC *aport)
{
    int rxch; /* word containing status info and char received from buffer */
    int index; /* index for skipping over unwanted characters */
    int ct; /* counter for the allocation of chars to a string */

    /* Read 21 characters before first bit of information. */
    /* (Beware for if async ignore on) */
    /* For the remaining assignments have a look at the position */
    /* calculation cyclic report format. */
    for (index = 1; index <= 22; index++)
    {
        /* only pass if receive a char from unempty buffer */
        do
        {
            rxch = async_rx(aport);
        } while ((rxch & B_RXEMPTY));

        ct = 0;
        while (((char)(rxch & 0xff)) != 'd') && (((char)(rxch & 0xff)) != ' ');
        {
            ainfo->tim[ct++] = rxch & 0xff;
            do
            {
                rxch = async_rx(aport);
            } while ((rxch & B_RXEMPTY));
        }
        ainfo->tim[ct] = '\0';

        ainfo->diff = rxch & 0xff;

        ct = 0;
        do
        {
            rxch = async_rx(aport);
            ainfo->lat[ct++] = rxch & 0xff;
        } while (((char)(rxch & 0xff)) != ' ');
        ainfo->lat[ct] = '\0';

        ct = 0;
        do
        {
            rxch = async_rx(aport);
            ainfo->lng[ct++] = rxch & 0xff;
        } while (((char)(rxch & 0xff)) != ' ');
    }
}

```

```

ainfo->lng[ct] = '\0';

ct = 0;
do
{
    rxch = async_rx(aport);
    while ((rxch & B_RXEMPTY));
    ainfo->hgt[ct++] = rxch & 0xff;
} while (((char)(rxch & 0xff)) != ' ');
ainfo->hgt[ct] = '\0';

ct = 0;
do
{
    rxch = async_rx(aport);
    while ((rxch & B_RXEMPTY));
    ainfo->pdp[ct++] = rxch & 0xff;
} while (((char)(rxch & 0xff)) != ' ');
ainfo->pdp[ct] = '\0';

for (index = 1; index <= 7; index++)
{
    do
    {
        rxch = async_rx(aport);
    } while ((rxch & B_RXEMPTY));

    ct = 0;
    do
    {
        rxch = async_rx(aport);
        ainfo->vvel[ct++] = rxch & 0xff;
    } while (((char)(rxch & 0xff)) != ' ');
    ainfo->vvel[ct] = '\0';

    ct = 0;
    do
    {
        rxch = async_rx(aport);
        while ((rxch & B_RXEMPTY));
        ainfo->hvel[ct++] = rxch & 0xff;
    } while (((char)(rxch & 0xff)) != ' ');
    ainfo->hvel[ct] = '\0';

    ct = 0;
    do
    {
        rxch = async_rx(aport);
        while ((rxch & B_RXEMPTY));
        ainfo->lng[ct++] = rxch & 0xff;
    } while (((char)(rxch & 0xff)) != ' ');
    ainfo->lng[ct] = '\0';

    rxch = async_rx(aport);
}

```

```
    )while ((rxch & B_RXEMPTY));
    ainfo->hdg[ct++] = rxch & 0xff;
    )while ((char)(rxch & 0xff) != ' ');
    ainfo->hdg[ct] = '\\0';

    for (index = 1; index <= 12; index++)
    {
        do
        {
            rxch = async_rx(aport);
        )while ((rxch & B_RXEMPTY));

        )
    }

    do
    {
        rxch = async_rx(aport);
    )while ((rxch & B_RXEMPTY));
    ct = 0;
    while ((char)(rxch & 0xff) != ' ')
    {
        ainfo->sat[ct++] = rxch & 0xff;
        do
        {
            rxch = async_rx(aport);
        )while ((rxch & B_RXEMPTY));
    }
    ainfo->sat[ct] = '\\0';

    return 0;
}
```

```

/* Flush the buffer, check if there is serial data
/* and find the beginning of a measurement. Baud lower limit is for */
/* time delay for this process to be greater than .35 secs. */
/* GPS will take longer than 1 second to take a measurement and send */
/* it.
#include "comm.h"
#include "condes.h"
#include <time.h>
#include <stdio.h>

int find_meas(ASYNC *aport, int *anoser)
{
    int rxch; /* word containing status info and char received from buffer */
    char msg = '\n'; /* char received from buffer */
    time_t first, second; /* Means of calculating time delay in finding */
                          /* the first char of the measurement. */

    async_rxflush(aport);
    first = time(NULL);

    /* Wait until get a char from empty buffer and it is '[' before */
    /* leaving function. */
    do
    {
        if (!((rxch = async_rx(aport)) & B_RXEMPTY))
            msg = (rxch & 0xff); /* apert here is an address */
                                /* Don't change msg if empty */
                                /* buffer.
        second = time(NULL);

        /* If time delay in finding the first char of the */
        /* measurement is longer than WAIT then return message that */
        /* there is no serial data. */
        if (difftime(second, first) > (double)WAIT)
        {
            *anoser = 1;
            break;
        }
    } while (msg != '[');
    return 0;
}

```

```

/* This function is aimed at using the control characters to log data to */
/* the specified file and to update the graphics screen with a suitable */
/* message. */

```

```

#include <stdio.h>
#include <graphics.h>
#include <conio.h>
#include <string.h>
#include "comdes.h"

```

```

extern int recmeas(FILE *, GPSREC *);
extern int recmeas(FILE *, GPSREC *, int *);
extern int recmeas(FILE *, GPSREC *, int *);
extern float cntrlat, cntrlng;
extern int grph_pts;

```

```

int control_logging(aold, acontrol, base, noser, ainfo, atag)
char *aold, *acontrol; /* control and old control chars */
const char *base; /* base file name */

```

```

const int noser; /* an indication of whether serial data exists */
GPSREC *ainfo; /* GPS parameter structure */
int *atag; /* information relating to what to tag a record with */
{

```

```

    static int xpos, ypos; /* locals NB else lose when leave function */
    char fno; /* to add to base filename */
    char file_name[15];
    char num[2]; /* for filename concatenation */
    static FILE *fpi;
    static int toggle = 0; /* an indication : MP is being logged or not */

```

```

    /* Close file if opened already by 'b' */
    /* and not instructed to stop logging with 'e'. */
    if ((*acontrol == 'q') || (*acontrol == 'Q')) && (*aold == 'b'))
        fclose(fp);

```

```

    /* For initial write to file or later when new write is requested */
    /* i.e. old = 'e'. */
    if ((*acontrol == 'b') && (*aold == 'e'))
    {

```

```

        /* Prompt for file no. to be appended to base name */
        xpos = grph_pts + 5;
        ypos = 200;
        bar(xpos, ypos - 60, xpos + 200, ypos + 60);
        outtextxy(xpos, ypos, "Enter the file no. (0..9) to ");
        ypos += 20;
        outtextxy(xpos, ypos, "which the data should be written.");
        /* scanf("%c", &fno);
        while(getchar() != '\n')
            continue; */ /* left out to prevent echo */
        fno = getch();
        num[0] = fno;
        num[1] = '\0';

```

```

        strcpy(file_name, "");
        strcat(file_name, base); /* file_name is a pointer to cat str */
        strcat(file_name, num);

```

```

        /* Open write file and goto begin */
        if((fp = fopen(file_name, "at")) == NULL)

```

```

    {
        cleardevice();
        printf("Can't open %s.\n", file_name);
        printf("Press any key to quit.");
        getch();
        *acontrol = 'q';
        return 1;
    }
    fseek(fp, 0L, SEEK_SET);

```

```

    /* Indicate the logging function and to which file */
    bar(xpos, ypos - 60, xpos + 200, ypos + 60);
    outtextxy(xpos, ypos, "Logging to file.....");

```

```

    /* Check if serial and error to text window if no data */
    if (noser == 1)
    {

```

```

        cleardevice();
        printf("No serial data Press a key to quit.");
        getch();
        fclose(fp);
        *acontrol = 'q';
        return 1;
    }

```

```

    /* Write structure to file */
    if ((*atag > 40) && (*atag < 65)) /* if tag info. indicates one of */
        /* the max of 24 samples */
        /* in sample tests. */
        recmeas(fp, ainfo, atag); /* Call write to file */
    /* function for sampling tests. */
    else
        recmeas(fp, ainfo); /* Write to file with no tag */

```

```

    *aold = *acontrol; /* To say this initial write has been done once */
    return 1;
}

```

```

/* For successive record logging to file. */
if ((*acontrol == 'b') && (*aold == 'b'))
{

```

```

    /* Check if serial data exists and error to text window if not */
    if (noser == 1)
    {

```

```

        printf("No serial data Press a key to quit.");
        getch();
        fclose(fp);
        *acontrol = 'q';
        return 1;
    }

```

```

    /* Write structure to file. */
    /* If either a begin or end tagging for MP has been requested or */
    /* a tag with '!' passed request, indicate on screen and log */
    /* record with tag. */
    if ((*atag == 32) || (*atag == 13))

```

```

(
    if (*atag == 32)
    (
        /* If not already logging MP */
        if (toggle == 0)
        (
            /* indicate that tagging records with MP */
            outtextxy(grph_pts + 10, 45, "LOGGING MP");
            toggle = 1;
        )
        else
        (
            /* clear the indication of MP logging */
            bar(grph_pts + 5, 40, grph_pts + 100, 60);
            toggle = 0;
        )
    )
    /* log record to file with MP tag or tagged with '*' */
    recmeas(fp, ainfo, atag);
)
if ((*atag > 40) && (*atag < 95)) /* If tag info. indicates one of */
    /* the max of 55 samples */
    /* in sample tests. */
    else
        recmeas(fp, ainfo, atag);
    recmeas(fp, ainfo);
)
/* For when a stop logging request is made. */
if ((*acontrol == 'e') && (*aold == 'b')) /* Old can only = 'b' if a */
    /* file has been opened. */
(
    /* clear logging message */
    bar(xpos, ypos - 60, xpos + 200, ypos + 60);
    outtextxy(xpos, ypos, "No logging taking place.");
    /* close file */
    fclose(fp);
    *aold = *acontrol; /* Both 'e' so this will be typed once. */
    cntrlat = 0.0; /* Re-initialize graphics at the end of */
    /* the logging. */
    cntrlng = 0.0;
)
return 0;
)

```

```
/* This function extracts the positioning info from the string structure */
/* item and converts it to a float value of position. */
```

```
#include <stdio.h>
#include "comdes.h"
```

```
int extract_posie(GPSREC *ainfo, float *alat, float *along)
```

```
{
    char *ptr; /* pointer to find the begin of a string */
```

```
    ptr = ainfo->lat;
    while (*ptr != ':') /* Only use the minutes part : */
        /* this form is within one degree. */
```

```
        ptr++;
    sscanf(++ptr, "%f", alat); /* whitespace no problem */
```

```
    ptr = ainfo->lng;
    while (*ptr != ':')
```

```
        ptr++;
    sscanf(++ptr, "%f", along);
```

```
    return 0;
}
```

```
/* This function converts a float lat and long */
/* value to graphic xy co-ordinates. */

extern int grph_pts;
extern float scale;
extern int cntrptx, cntrpty;
extern float cntrlat, cntring;

int getxy(float lat, float lng, int *ax, int *ay)
{
    int latpts, lngpts;

    /* If longitude has changed then calculate the difference in */
    /* graph points. */
    if ((cntring - lng) == 0.0)
        lngpts = 0;
    else
        lngpts = (int)((cntring - lng)/scale * grph_pts/2);

    /* Similarly for latitude */
    if ((cntrlat - lat) == 0.0)
        latpts = 0;
    else
        latpts = (int)((cntrlat - lat)/scale * grph_pts/2);

    /* calculate the absolute graph co-ordinates */
    *ay = cntrpty - latpts;
    *ax = cntrptx - lngpts;

    return 0;
}
```

```

/* This function searches for the beginning of the next cyclic report. */
#include "comm.h"

int sbegin(ASYNC *aport, char *amesg)
{
    int rxch; /* Contains the character as well as the status word */
              /* from the ring buffer. */

    async_rxfush(aport); /* Clear the buffer : It is necessary not to */
                        /* lose characters due to */
                        /* re-initializing pointers in the ring buffer.*/

    /* Enter an infinite loop that is broken by the receiving of a space */
    /* following a newline : marking the beginning of a new record. */
    for(;;)
    {
        do
        {
            if (!((rxch = async_rx(aport)) & B_RXEMPTY))
                *amesg = (rxch & 0xff); /* aport here is an address. */
            /* Don't assign mesg unless */
            /* buffer is not empty. */
        } while (*amesg != '\n'); /* Wait until get a char from */
                                /* unempty buffer that is a newline. */

        do
        {
            rxch = async_rx(aport);
        } while ((rxch & B_RXEMPTY)); /* Only pass if receive a */
                                /* char from unempty buffer. */
        if ((*amesg = rxch & 0xff) == ' ') /* check for the space char */
            break;
    }

    return 0;
}

```



```
/* This function writes GPS structure elements into a suitable file with */
/* a sample no. tag. */
```

```
#include <stdio.h>
#include "codes.h"
```

```
int rcmeass(FILE *fp, GPSREC *ainfo, int *atag)
```

```
{
    int temp;
```

```
    fputs(ainfo->tim, fp);
    putc(' ', fp);
```

```
    if (ainfo->diff == 'd') /* Set the diff field to 'n' if no 'd' */
        putc(ainfo->diff, fp); /* in measurement. */
```

```
    else
```

```
        putc('n', fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->lat, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->lng, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->hgt, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->pdp, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->vvel, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->hvel, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->hdg, fp);
```

```
    putc(' ', fp);
```

```
    fputs(ainfo->sat, fp);
```

```
    putc(' ', fp);
```

```
/* Subtract the offset originally added to the sample no. to move */
```

```
/* it out of the ascii char no. range used for other tagging info. */
```

```
temp = *atag - 40;
```

```
fprintf(fp, "%d\n", temp);
```

```
    return 0;
}
```

```

/* This function writes measurement info to a suitable file */
/* and interprets the space and enter keystroke ascii */
/* character numbers as a MP and asterisk tag respectively. */

#include <stdio.h>
#include "comdes.h"

extern int grph_pts;

int recmeast(FILE *fp, GPSREC *ainfo, int *atag)
{
    static int toggle = 0; /* Toggle to design the tag as either MP */
    /* begin or end. */

    if (*atag == 13) /* If tagging info is a 'enter'....*/
    {
        fputs(ainfo->tim, fp);
        putc(' ', fp);

        if (ainfo->diff == 'd') /* Set the diff field to 'n' if no 'd' */
            putc(ainfo->diff, fp); /* in measurement. */
        else
            putc('n', fp);
        putc(' ', fp);

        fputs(ainfo->lat, fp);
        putc(' ', fp);
        fputs(ainfo->lng, fp);
        putc(' ', fp);
        fputs(ainfo->hgt, fp);
        putc(' ', fp);
        fputs(ainfo->pdp, fp);
        putc(' ', fp);
        fputs(ainfo->vvel, fp);
        putc(' ', fp);
        fputs(ainfo->hvel, fp);
        putc(' ', fp);
        fputs(ainfo->hdg, fp);
        putc(' ', fp);
        fputs(ainfo->sat, fp);
        putc(' ', fp);
        fputs("MP", fp); /* .....tag with an asterisk */
        *atag = 'n';
    }
    if (*atag == 32) /* If tagging info is a 'space'... */
    {
        fputs(ainfo->tim, fp);
        putc(' ', fp);

        if (ainfo->diff == 'd') /* Set the diff field to 'n' if no 'd' */
            putc(ainfo->diff, fp); /* in measurement. */
        else
            putc('n', fp);
        putc(' ', fp);

        fputs(ainfo->lat, fp);
        putc(' ', fp);
        fputs(ainfo->lng, fp);
        putc(' ', fp);
        fputs(ainfo->hgt, fp);
    }
}

```

```

        putc(' ', fp);
        fputs(ainfo->pdp, fp);
        putc(' ', fp);
        fputs(ainfo->vvel, fp);
        putc(' ', fp);
        fputs(ainfo->hvel, fp);
        putc(' ', fp);
        fputs(ainfo->hdg, fp);
        putc(' ', fp);
        fputs(ainfo->sat, fp);
        putc(' ', fp);
        /* ..... tag with the suitable MP tag */
        if (toggle == 0)
        {
            fputs("MP", fp);
            toggle = 1;
        }
        else
        {
            fputs("<MP", fp);
            toggle = 0;
        }
    }
    *atag = 'n'; /* Reset the tag so that no */
    /* tagging will occur until the next request. */
    return 0;
}

```

G.2 Post Processing Software

The output files generated by this software are not provided as it too would amount to about 5 stiffy disks worth.

SIMULM.PRJ enables the graphical simulation of the logged positions to retrace the movements made on the farm.

The following software printouts are all the programs in the SIMULM.PRJ project file.

```

/* This program will read data from a file and output it */
/* graphically to represent and re-enact it's capture. */
/* Extracting information from the file will also include */
/* the option to detect tagged records and circle those positions. */
/* The program will be modified for each tailor made application of it. */

```

```

#include <dos.h>
#include <conio.h>
#include <time.h>
#include <stdio.h>
#include <stdlib.h>
#include <graphics.h>

/* graphics external variables */
int grph_pts; /* For translating real position.... */
float scale; /* to a graphics position. */
int cntrptx, cntrpty; /* screen centre or starting points */
float cntrlat, cntrlng; /* associated centre lat and long */

```

```

/* external functions */
extern int extract_poste(FILE *, float *, float *, int *);
extern int getxy(const float, const float, int *, int *);
extern int setupscreen(void);

```

```

int main(void)
{

```

```

    /* input file logged during tests */
    FILE *fp;
    char *name = "simdata";

```

```

    /* graphics variables */
    int xpos, ypos; /* position on graphics screen for prompting and set up */
    float lat, lng; /* real position */
    int oldx, oldy, x, y; /* calculated and previous graphics position */
    int star; /* tagged records */

```

```

    clrscr();

```

```

    /* open input file and goto begin */
    if((fp = fopen(name, "r")) == NULL)
    {
        printf("Can't open %s.\n", name);
        exit(1);
    }
    fseek(fp, 0L, SEEK_SET);

```

```

    setupscreen(); /* graphics screen */

```

```

    /* prompt */
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Strike a key to stop graphics and another to quit.");
    /* set view box */

```

```

    setviewport(xpos, ypos + 30, xpos + (getmaxx() - (ypos + 30)), getmaxy(), 1);
    setfillstyle(SOLID_FILL, EGA_WHITE);
    grph_pts = getmaxy() - (ypos + 30);
    bar3d(0, 0, grph_pts, grph_pts, 0, 0);

```

```

    scale = 0.054545; /* approx 1cm of 55cm of 3min at 1: 10000 is 100m */

```

```

    /* start point */
    cntrptx = (int)grph_pts*.5;
    cntrpty = (int)grph_pts*.99;

```

```

    /* indication that no points in the file have yet been processed */
    cntrlat = 0.0;
    cntrlng = 0.0;

```

```

    while (!kbhit())
    {

```

```

        delay(1); /* So can watch the drawing or simulate the */
        /* capture as it was in the tests. */

```

```

        if (getc(fp) == EOF)
            break;

```

```

        /* Extract a float value for lat and long from logged data. */
        extract_poste(fp, &lat, &lng, &star);

```

```

        /* if first extracted point, assign lat and long to startpoint */
        if (cntrlat == 0.0)
        {

```

```

            cntrlat = lat;
            cntrlng = lng;
            oldx = cntrptx;
            oldy = cntrpty;

```

```

        } /* else plot new point and circle it if the point is tagged */
        else
        {

```

```

            getxy(lat, lng, &y, &x); /* Get equivalent graph position */
            moveto(x, y);
            lineTo(x, y);
            if (star == 1)
                circle(x, y, 3);

```

```

            oldx = x;
            oldy = y;

```

```

        }

```

```

    }
    sound(440);
    delay(500);
    nosound();
    getch();
    fclose(fp);
    closegraph();

```

)
return 0;

```
/* This function extracts the positioning info from the logged records. */  
/* It also detects for a tagged record and sets a 'star' flag according */  
/* to whether it was tagged as a waypoint or to indicate the beginning */  
/* or end of possible multipath tagging. */
```

```
#include <stdio.h>
```

```
int extract_posie(FILE *fp, float *alat, float *along, int *astar)
```

```
{  
    char ch;  
    *astar = 0;  
  
    while (getc(fp) != ' ' )  
        continue;  
  
    while (getc(fp) != ':')  
        continue;  
    fscanf(fp, "%f", alat);  
  
    while (getc(fp) != ':')  
        continue;  
    fscanf(fp, "%f", along);  
  
    while ((ch = getc(fp)) != '\n')  
    {  
        if (ch == '*') /* tagged waypoint */  
            *astar = 1;  
        if (ch == '<') /* tagged MP begin */  
            *astar = 2;  
        if (ch == '>') /* tagged MP end */  
            *astar = 3;  
        continue;  
    }  
  
    return 0;  
}
```

```
/* This function gets the absolute graphic position from a float */
/* lat and long */

extern int grph_pts;
extern float scale;
extern int cntrptx, cntrpty;
extern float cntrlat, cntrlng;

int getxy(float lat, float lng, int *ay, int *ax)
{
    int latpts, lngpts;

    /* Calculates graph points if the position information is */
    /* removed from the start position. */
    if ((cntrlng - lng) == 0.0)
        lngpts = 0;
    if (cntrlng != lng)
        lngpts = (int)((cntrlng - lng)/scale * grph_pts/2);

    if ((cntrlat - lat) == 0.0)
        latpts = 0;
    if (cntrlat != lat)
        latpts = (int)((cntrlat - lat)/scale * grph_pts/2);

    /* calculate the absolute position of the point on the graphics screen */
    *ay = cntrpty - latpts;
    *ax = cntrptx - lngpts;

    return 0;
}
```

```
/* To set up graphics screen */
#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>

int setupscreen(void)
(
    /* request auto detection */
    int gdriver = DETECT, gmode, errorcode;

    /* initialize graphics and local variables */
    initgraph(&gdriver, &gmode, "");

    /* read result of initialization */
    errorcode = graphresult();
    if (errorcode != grOk) /* an error occurred, print to screen */
    (
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt:");
        getch(); /* nice way to let you pass to end a non recurring process */
        exit(1); /* terminate with an error code */
    )

    /* set up graphics variables */
    cleardevice();
    settextstyle(SMALL_FONT, HORIZ_DIR, 0);
    setfillstyle(SOLID_FILL, EGA_WHITE);
    bar3d(0, 0, getmaxx(), getmaxy(), 0, 0);
    setcolor(EGA_BLACK);
    setusercharsize(7, 8, 5, 4);
    settextjustify(LEFT_TEXT, CENTER_TEXT);

    return 0;
)
```


STATDTA.PRJ enables the re-selection of specific records and specified fields within those logged records based upon the tagging information within a record. The filtered data was manipulated to a more usable form and written to output files.

The following software printouts are all the programs in the STATDTA.PRJ project file.

```

/* This program extracts only the relevant information from logged records */
/* for later processing. */
/* The program can also be modified to only select tagged records or tagged */
/* records and the previous record. */

#include <stdio.h>
#include <conio.h>
#include <dos.h>
#include <stdlib.h>

```

```

/* externally referenced functions in other files*/
extern int extract_posie(FILE *, float *, float *, float *, int *, char *, char *,
float *);

```

```

int main(void)
{

```

```

    FILE *fp, *fpo;
    char *name = "statdata"; /* logged data from tests */
    char *oname = "statrep"; /* Output data file containing */
                          /* extracted records. */

```

```

    char slat[20];
    char slng[20];
    float lat, lng, hgt, brg;
    float tlat, tlng, thgt, tbrg = 0.0; /* Temporary variables for */
    /* maintaining information from the previous record. */
    int star = 0; /* flag for tagged waypoints */
    int ct = 0;
    char cntrl = 'n';

```

```

    clrscr();

```

```

    /*open input file and goto begin*/
    if((fp = fopen(name, "r")) == NULL)
    {
        printf("Can't open %s.\n", name);
        exit(1);
    }

```

```

    fseek(fp, 0L, SEEK_SET);

```

```

    /*open output file and goto begin*/
    if((fpo = fopen(oname, "w")) == NULL)
    {
        printf("Can't open %s.\n", oname);
        exit(1);
    }
    fseek(fpo, 0L, SEEK_SET);

```

```

    while (cntrl != 'q')
    {
        delay(1);

```

```

        if(kbhit())
            cntrl = getch();
        if (getc(fp) == EOF)
            cntrl = 'q';
        if (cntrl != 'q')
            /* Extract only the required information from */
            /* a record in a meaningful form. */
            extract_posie(fp, &lat, &lng, &hgt, &star, slat, slng, &brg);
        /* Option to detect whether a record was tagged */
        /* with 'passing a waypoint' information. */
        if (star == 1)
        {
            /* Output previous record and current record */
            /* to be filed for processing. */
            fprintf(fpo, "%d -33 %f 18 %f %f %f\n", ++ct, tlat, tlng,
            thgt, tbrg);
            fprintf(fpo, "%d -33 %f 18 %f %f %f\n", ++ct, lat, lng, hgt
            , brg);
        }
        /*
        /* Record the current record for prosperity */
        tlat = lat;
        tlng = lng;
        thgt = hgt;
        tbrg = brg;
    }
    sound(440);
    delay(500);
    nosound();
    fclose(fp);
    return 0;
}

```

```

/* This function extracts the relevant info from the logged test records */
/* in a meaningful form. */

#include <stdio.h>

int extract_posie(FILE *fp, float *alat, float *alng, float *ahgt, int *astar, char
ar *stat, char *sing, float *abrg)
{
    char ch;
    char *ptr;
    char temp[20];
    int i;

    *astar = 0; /* flag for tagged records */

    while (getc(fp) != ' ')
        continue;

    /* extract latitude to a string */
    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%10s", slat);

    /* extract lat float from string */
    ptr = slat;
    while (*ptr != ':')
        ptr++;
    sscanf(++ptr, "%f", alat);

    /* simply for long */
    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%11s", slng);
    ptr = slng;
    while (*ptr != ':')
        ptr++;
    sscanf(++ptr, "%f", alng);

    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%f", ahgt);

    /* Include option for bearing info. extraction so that */
    /* it can be used for processing. */
    for(i=0; i<5; i++)
    {
        while (getc(fp) != ' ')
            continue;
        fscanf(fp, "%f", &temp);
    }

    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%f", abrg);

    while ((ch = getc(fp)) != '\n')
    {
        if (ch == '*') /* set flag if tagged waypoint */
            *astar = 1;
        if (ch == '<') /* set flag if tagged MP begin */

```

```

            *astar = 2;
        if (ch == '>') /* set flag if tagged MP end */
            *astar = 3;
        continue;
    }

    return 0;
}

```

STATM.PRJ enables statistics to be calculated for each of the soil samples.

The following software printouts are all the programs in the STATM.PRJ project file.

```

while (cntrl != 'q')
{
    delay(1);
    next_sample = 0; /* Set flag to represent still */
    /* reading the same sample's records. */
    if(kbhit())
        cntrl = getch();
    /* extract the relevant info. from GPS logged records */
    extract_posie(fp, &lat, &lng, &star, &slat, &sing, &next_sample);
    if (getc(fp) == EOF)
    {
        next_sample = 1;
        cntrl = 'q';
    }
    /* Use the record's info. to add to summers or to calculate the */
    /* stats depending on whether we are summing or calculating. */
    /* sample have been received. */
    statcalc(fpo, fpg, &lat, &lng, &next_sample); /* GIS doesn't need hgt d
ata */
}
sound(440);
delay(500);
nosound();
fclose(fp);
fclose(fpg);
fclose(fpo);
return 0;
}

```

```

/* This program will be used in various forms to determine the */
/* average and spread of the data from a GPS receiver. */
/* This version allows stats to be determined from each soil sample. */

#include <stdio.h>
#include <conio.h>
#include <dos.h>
#include <stdlib.h>

/* externally referenced functions in other files*/
extern int extract_posie(FILE *, float *, float *, int *, char *, char *, int *);
extern int statcalc(FILE *, FILE *, float *, float *, int *);

int main(void)
{
    FILE *fp, *fpo, *fpg;
    char *name = "statdata"; /* logged records from the GPS receiver */
    char *name = "statrep"; /* for a report of the results */
    char *name = "gisdata"; /* Output file of sample point positions */
    /* in a form compatible with a GIS application. */
    char stat[20]; /* string representations of positioning info. */
    char sing[20]; /* float representations of positioning info. */
    float lat, lng; /* integer representing what the record was tagged with */
    int star; /* flag to detect when the input file contains records */
    int next_sample; /* of the next sample point. */
    char cntrl = 'n';

    clrscr();

    /*open input file and goto begin*/
    if((fp = fopen(name, "r")) == NULL)
    {
        printf("Can't open %s.\n", name);
        exit(1);
    }
    fseek(fp, 0L, SEEK_SET);

    /*open output record file and goto begin*/
    if((fpo = fopen(ename, "w")) == NULL)
    {
        printf("Can't open %s.\n", ename);
        exit(1);
    }
    fseek(fpo, 0L, SEEK_SET);

    /*open output GIS file and goto begin*/
    if((fpg = fopen(gname, "w")) == NULL)
    {
        printf("Can't open %s.\n", gname);
        exit(1);
    }
    fseek(fpg, 0L, SEEK_SET);

```

```
/* This function extracts the positioning info from the logged GPS */
/* positioning info. */

#include <stdio.h>

int extract_posie(FILE *fp, float *alat, float *alng, int *astar, char *slat, char
 *sing, int *anext_sample)
(
    char ch, temp; /* for assigning positioning info. to a string. */
    char *ptr; /* Record of what the last record was */
    static char oldtemp = ' '; /* tagged with : sample no.*/

    *astar = 0; /* represents the kind of tagging info. */

    while (getc(fp) != ' ')
        continue;

    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%10s", slat);

    ptr = slat;
    while (*ptr != ':')
        ptr++;
    sscanf(++ptr, "%f", alat);

    while (getc(fp) != ' ')
        continue;
    fscanf(fp, "%11s", sing);
    ptr = sing;
    while (*ptr != ':')
        ptr++;
    sscanf(++ptr, "%f", alng);

    while ((ch = getc(fp)) != '\n')
    (
        if (ch == '*') /* case of waypoint tag */
            *astar = 1;
        if (ch == '<') /* case of MP begin tag */
            *astar = 2;
        if (ch == '>') /* case of MP end tag */
            *astar = 3;
        temp = ch; /* second last char : in this case sample no. tag */
        continue;
    )

    /* if new sample records are being read, update next sample flag */
    if (temp != oldtemp)
    (
        *anext_sample = 1;
        oldtemp = temp;
    )

    return 0;
}
```

```

/* This program calculates the mean and std dev of a number of floats */
/* and writes the stats to a file in the correct format. */
/* This program either adds the input to summers if still reading the */
/* 'same sample' records from the input file or calculates the stats of a */
/* sample point if all the recors of a articular sample have been read. */

#include <stdio.h>
#include <math.h>

int statcalc(FILE *fpo, FILE *fpu, float *alat, float *alng, int *anext_sample)
{
    /* sums of errors, sums of squared errors and mean position */
    static double latsum, lngsum, latsumsqsum, lngsumsqsum, latmean, lngmean = 0.0;
    double latstdv, lngstdv; /* Standard deviation for position info. */
    static int num = 0; /* in geographical co-ords in one dimension only. */
    static int ct = 1; /* number of records for one sample point */
    /* for the numbering of the sample points */

    /* If all the sample records of the last sample point have been */
    /* read, calculate the stats. */
    if (*anext_sample == 1)
    {
        /* calc mean and std dev and print mean to file for GIS and a report */
        latmean = latsum/num;
        lngmean = lngsum/num;

        latstdv = sqrt(((num*(latsumsqsum)-pow(latsum, 2))/(num*(num-1))));
        lngstdv = sqrt(((num*(lngsumsqsum)-pow(lngsum, 2))/(num*(num-1))));

        printf(fpo, "%d %d %f %f %g %g\n", ct, num, latmean, lngmean, latstd
        v, lngstdv);
        printf(fpg, "-33 41 %f 18 38 %f\n", ((latmean - 41) * 60), ((lngmean -
        38) * 60));

        /* start the stat sums for the next sample */
        latsum = *alat;
        lngsum = *alng;
        latsumsqsum = pow(*alat, 2);
        lngsumsqsum = pow(*alng, 2);
        num = 1;
        ct++;
    }
    /* else add to the stat summers */
    else
    {
        latsum += *alat;
        lngsum += *alng;
        latsumsqsum += pow(*alat, 2);
        lngsumsqsum += pow(*alng, 2);
        num++;
    }

    return 0;
}

```

STATST.PRJ is a variation of STATM.PRJ for the determination of the statistics for the logged static data.

The following software printouts are all the programs in the STATST.PRJ project file.


```
/* This program will be used in various forms to determine the */
/* average and spread of the data from GPS.
```

```
/* This version will be used to process the static data.*/
```

```
#include <stdio.h>
#include <math.h>
#include <conio.h>
#include <dos.h>
#include <stdlib.h>
```

```
/* externally referenced functions in other files*/
extern int extract_posite(FILE *, double *, double *, double *, double *);
extern int statcalc(FILE *, double *, double *, double *, double *, double *);
```

```
/* external variables for stats function */
```

```
double latmean = 0.0;
double lngmean = 0.0;
double hgtmean = 0.0;
double pdopmean = 0.0;
double sumerr = 0.0; /* sum of errors */
double sumerrsq = 0.0; /* sum of errors squared */
double psumerr = 0.0; /* Simply for another parameter */
double psumerrsq = 0.0; /* of the GPS cyclic report string. */
double psumerrsq = 0.0;
```

```
int main(void)
```

```
{
```

```
FILE *fpg, *fpo;
char *gssname = "statstr"; /* input data extracted from the logged test data */
char *oname = "statsrep"; /* report */
```

```
/* Variables required for position accuracies and for the */
/* determination of the stats of other parameters of interest */
```

```
/* in the GPS cyclic report string. */
double lat, lng, hgt;
double pdop;
```

```
/* sum of errors from the mean */
double latsum = 0.0; /* must do initializing separate */
double lngsum = 0.0;
double hgtsum = 0.0;
double pdopsum = 0.0;
```

```
double meanerr, stddev; /* average error and the standard deviation */
long num = 0; /* number of samples used in stats */
```

```
clrscr();
```

```
/* Open input file of position readings in geographical co-ordinates */
```

```
/* and goto begin. */
```

```
if((fpg = fopen(gssname, "r")) == NULL)
```

```
{
```

```
printf("Can't open %s.\n", gssname);
```

```
exit(1);
```

```
}
```

```
fseek(fpg, 0L, SEEK_SET);
```

```
/* open output file for report and goto begin */
if((fpo = fopen(oname, "w")) == NULL)
```

```
{
```

```
printf("Can't open %s.\n", oname);
```

```
exit(1);
```

```
}
fseek(fpo, 0L, SEEK_SET);
```

```
/* Header in report */
```

```
fprintf(fpo, "THESE ARE THE RESULTS FOR THE STATIC MEASUREMENTS \n"
"THE DATA SET IS TAKEN FROM THE STATIC READINGS AT ONE POINT \n"
"THE ERRORS AND STATS WERE CALCULATED 2 DIMENSIONALLY \n");
```

```
fprintf(fpo, "\n");
```

```
num = 0; /* count the number of records used */
```

```
/* calculate the mean for all the data points */
for (;;)
{
```

```
extract_posite(fpg, &lat, &lng, &hgt, &pdop);
```

```
if ((pdop < 4.977473) && (pdop > 3.834729))
if ((pdop >= 4.977) /* && (pdop <= 4.977) */ /* filters */
```

```
{
latsum += lat;
lngsum += lng;
hgtsum += hgt;
pdopsum += pdop;
num++;
```

```
} if (getc(fpg) == EOF)
break;
```

```
} printf("%ld \n", num);
```

```
latmean = latsum/num;
```

```
lngmean = lngsum/num;
```

```
hgtmean = hgtsum/num;
```

```
pdopmean = pdopsum/num;
```

```
printf("%f %f %f %f \n", latmean, lngmean, hgtmean, pdopmean);
```

```
rewind(fpg);
```

```
/* Using the mean data : errors can be calculated. */
```

```
/* Do the following for each record. */
```

```
for(;;
```

```
{
```

```

/* Extract Y, X, and hgt. */
extract_posie(fpg, &lat, &lng, &hgt, &pdop);

fprintf(fpo, "STATIC: Y: %f X: %f HGT: %f\n", Y, X, hgt); */

/* if ((pdop < 4.977473) && (pdop > 3.834729)) */
/* if ((pdop >= 4.977)) */
/* statcalc(fpo, &lat, &lng, &hgt, &pdop); */
/* add to the summers */

if (getc(fpg) == EOF)
    break;
}
printf("\n");

/* Calc the avg error from the mean error and the std dev from the sum of */
/* the squared errors. */
meanerr = sumerr / num;
stddev = sqrt(sumerrsq / (num - 1));

/* write results to a report */
fprintf(fpo, "\n");
fprintf(fpo, "MEAN ERROR IS : %f\n", meanerr);
fprintf(fpo, "STD DEV : %f\n", stddev);

/* calc pdop mean error and std dev */
meanerr = psumerr / num;
stddev = sqrt(psumerrsq / (num - 1));

/* write results to a report */
fprintf(fpo, "\n");
fprintf(fpo, "MEAN PDOP ERROR IS : %f\n", meanerr);
fprintf(fpo, "PDOP STD DEV : %f\n", stddev);

sound(440);
delay(500);
nosound();
getch();
fclose(fpg);
fclose(fpo);

return 0;
}

```

```
/* This function extracts the positioning info from records extracted */  
/* from the original logged data. */
```

```
#include <stdio.h>
```

```
int extract_posie(FILE *fp, double *alat, double *alng, double *ahgt, double *apd  
op)  
{  
    float temp;  
  
    fscanf(fp, "%f", &temp);  
    fscanf(fp, "%f", &temp);  
    fscanf(fp, "%lf", alat);  
    fscanf(fp, "%f", &temp);  
    fscanf(fp, "%lf", alng);  
    fscanf(fp, "%lf", ahgt);  
    fscanf(fp, "%lf", apdop);  
  
    return 0;  
}
```

```

/* This program calculates the sums of the errors squared for position */
/* accuracy estimation and for statistics relating to another parameter */
/* in the GPS string. */

#include <stdio.h>
#include <math.h>

extern double latmean, lngmean, hgtmean;
extern double pdopmean;
extern double sumerr, sumerrsq;
extern double psumerr, psumerrsq;

int statcalc(FILE *fpo, double *alat, double *alng, double *ahgt, double *apdop)
{
    double errsq = 0.0;
    double perrsq = 0.0;

    /* These constants were estimated to convert geographical positioning */
    /* information to the gauss conform equivalent without using the */
    /* transformation software to do it. */
    float latslope = 1843.2282;
    float lngslope = -1551.948052;

    /* adjust the equation depending on whether 2D or 3D stats are required */
    errsq = pow((( *alat - latmean)*latslope),2) + pow((( *alng - lngmean)*lngslope),2);
    /* fprintf(fpo, "ERROR STATIC : %f \n", sqrt(errsq)); */
    perrsq = pow(( *apdop - pdopmean),2);

    psumerrsq += perrsq;
    psumerr += sqrt(perrsq);

    sumerrsq += errsq;
    sumerr += sqrt(errsq);

    return 0;
}

```

STADYN.PRJ determined the statistics for the logged dynamic points. The input files were generated by STATDTA.PRJ and this program did all the necessary compensation etc. and generated the statistics using the surveyed data.

The following software printouts are all the programs in the STADYN.PRJ project file. The file EXTRACDY.C can be found in the project file STATST.PRJ and so is not repeated in this project's listing.

```

/* This program will be used in various forms to determine the */
/* average and spread of the data from GPS

/* This version corrects the processed (gauss) dynamic measurements */
/* according to the measuring technique dimensions and current bearing.*/
/* It then averages two measurements for each logged waypoint (and if */
/* applicable (road), does the same for those taken when moving in the */
/* opposite direction) to get an estimate of the recorded dynamic position.*/
/* The points grossly out were removed before being processed here. */
/* These readings were used to calculate an estimate of the */
/* average error and std dev of the error for the dynamic case.*/

#include <stdio.h>
#include <math.h>
#include <conio.h>
#include <dos.h>
#include <stdlib.h>

```

```

/* externally referenced functions in other files*/

```

```

extern int extract_posie(FILE *, double *, double *, double *);
extern int extract_brg(FILE *, double *);
extern int statcalc(FILE *, FILE *, double *, double *, double *, double *, double *, double *);

```

```

int main(void)
{

```

```

    FILE *fps, *fpg1, *fpg, *fpg1, *fpg, *fpg;
    char *stdname = "dynstd"; /* file of surveyed points for reference */
    char *gssname = "dynss"; /* file with extracted info for stake on RHS. */
    char *brgname = "dynbrg"; /* ...and the bearing info. */
    char *gss1name = "dynss1"; /* simply for LHS */
    char *brg1name = "dynbrg1";
    char *oname = "dynrep"; /* output a report */
    double y, x, hgt, brg;
    double ysum, xsum, hgtsum, brgsum;
    double theta; /* For measuring technique compensation using the */
    /* bearing info. */
    float l, anthgt; /* length of stake and GPS antenna height from ground */
    double yp[55], xp[55], hgt[55]; /* array of positioning info for RHS */
    double ypl[55], xpl[55], hgtpl[55]; /* simply for LHS */
    int i;

```

```

    clrscr();

```

```

/*open input file of reference positions and goto begin*/
/* std file for road point numbers in order 123456987 */
if((fps = fopen(stdname, "r")) == NULL)
{

```

```

    printf("Can't open %s.\n", stdname);
    exit(1);
}

```

```

fseek(fps, 0L, SEEK_SET);

```

```

/*open input file of gauss readings (RHS) and goto begin*/
if((fpg = fopen(gssname, "r")) == NULL)

```

```

{
    printf("Can't open %s.\n", gssname);
    exit(1);
}

fseek(fpg, 0L, SEEK_SET);

/*open input file of gauss readings (LHS) and goto begin*/
/* if((fpg1 = fopen(gss1name, "r")) == NULL)
{
    printf("Can't open %s.\n", gss1name);
    exit(1);
}

fseek(fpg1, 0L, SEEK_SET);

/*open input file containing the bearings of RHS readings and goto begin*/
if((fpg = fopen(brgname, "r")) == NULL)
{
    printf("Can't open %s.\n", brgname);
    exit(1);
}
fseek(fpg, 0L, SEEK_SET);

/*open input file containing the bearings of LHS readings and goto begin*/
/* if((fpg1 = fopen(brg1name, "r")) == NULL)
{
    printf("Can't open %s.\n", brg1name);
    exit(1);
}
fseek(fpg1, 0L, SEEK_SET);

/*open output file for report and goto begin*/
if((fpo = fopen(oname, "w")) == NULL)
{
    printf("Can't open %s.\n", oname);
    exit(1);
}
fseek(fpo, 0L, SEEK_SET);

/* do for the RHS */
/* for each waypoint */
i = 1; /* road case : would count down for point in order 789654321 */
anthgt = 2.92 + 6.52;
l = 1.07;

/* do the following for every pair if records */
for(;;)
{
    /*Extract y, x, and hgt from file of selected records in gauss form*/
    extract_posie(fpg, &y, &x, &hgt);
    /*Extract bearing info.*/
    extract_brg(fpg, &brg);
    ysum = y;

```

```

xsum = x;
hgtsum = hgt;
brgsum = brg;

extract_posie(fpg, &y, &x, &hgt);
extract_brg(fpb, &brg);

/* Average the two and */
/* correct the average according to the position of the stake. */
if (((theta = ((brgsum + brg)/2 + 90)) * M_PI/180) > 2 * M_PI)
    theta = theta - 2 * M_PI;

yp1[i] = (ysum + y)/2 - l * sin(theta);
printf("%f", yp1[i]);
xp1[i] = (xsum + x)/2 - l * cos(theta);
printf("%f", xp1[i]);
hgtpl[i] = (hgtsum + hgt)/2 - anthgt;
printf("%f", hgtpl[i]);
i++;
if (getc(fpg) == EOF)
    break;
}
printf("\n");

/* do for the LHS */
i = 1; /* count up for point in order 123456987 */
i = 9; /* count down for static road */

anthgt = 2.92 + 6.52;
l = 1.07;

/* do the following for each waypoint */
{
    /*Extract Y, X, and hgt from file of selected records in gauss form*/
    extract_posie(fpg1, &y, &x, &hgt);
    /*Extract bearing info.*/
    extract_brg(fpb1, &brg);

    ysum = y;
    xsum = x;
    hgtsum = hgt;
    brgsum = brg;

    extract_posie(fpg1, &y, &x, &hgt);
    extract_brg(fpb1, &brg);

    /* Average the two and */
    /* correct the average according to the position of the stake. */
    if (((theta = ((brgsum + brg)/2 - 90)) * M_PI/180) < 0)
        theta = theta + 2 * M_PI;

    yp1[i] = (ysum + y)/2; /* - l * sin(theta); */
    printf("%f", yp1[i]);
    xp1[i] = (xsum + x)/2; /* - l * cos(theta); */
    printf("%f", xp1[i]);
    hgtpl[i] = (hgtsum + hgt)/2 - anthgt;
    printf("%f", hgtpl[i]);
}

```

```

i++;
if (getc(fpg1) == EOF)
    break;
}

/* Use the averaged and corrected estimate of the waypoints to */
/* determine the statistics with respect to the surveyed reference */
/* points. */
statcalc(fpo, fps, yp, yp1, xp, xp1, hgt, hgtpl);

sound(440);
delay(500);
nosound();
getch();
fclose(fpg);
fclose(fpg1);
fclose(fps);
fclose(fpb);
fclose(fpb1);
return 0;
}

```

```
/* This function extracts the bearing info from records extracted from the */  
/* original logged data. */
```

```
#include <stdio.h>  
  
int extract_brg(FILE *fp, double *abrg)  
{  
    char temp[20];  
    int i;  
  
    for (i=1; i<6; i++)  
    {  
        fscanf(fp, "%s", &temp);  
    }  
  
    fscanf(fp, "%lf", abrg);  
  
    while (getc(fp) != '\\n')  
        continue;  
  
    return 0;  
}
```


KRIG.PRJ generated files of interpolated data based upon sample value information. The program made use of the semivariogram functions, the data for which was determined by means of a variation of this software.

The following software printouts are all the programs in the KRIG.PRJ project file.

```

/* This program serves to interpolate sampled data at a number of points */
/* between samples using the kriging technique and a model for the */
/* semivariogram of the chemical to be interpolated. */

#include <stdio.h>
#include <malloc.h>
#include <conio.h>
#include <stdlib.h>
#include "krigenst.h"

float sample[COLS][ROWS]; /* Contains sample values at each sample site. */
float z[SIZE]; /* External matrix assigned by means of a separate function */
/* with the values of the neighbouring sample values for each */
/* interpolated point. */

/* externally referenced functions */
extern int samst(int (*funcptr)(double dum1, double dum2, double dum3, double du
m4, int *dum5, float dum1), double onrow, double oncol, double rowval, double co
lval, double prevrow, double prevcol, int *asum, float vector[]);
extern int calca(double refrow, double refcol, double neighrow, double neighcol,
int *aj, float a[]);
extern int calcb(double row, double col, double refrow, double refcol, int *asum,
float b[]);

/* functions for matrix algebra */
void ludcmp(float **a, int n, int *indx, float *d);
void lubksb(float **a, int n, int *indx, float *d);
float *vector(int, int);
int *ivector(int, int);
void free_vector(float *, int, int);
void free_ivector(int *, int, int);
void nreor(char *);
float **matrix(int, int, int, int);
void free_matrix(float *, int, int, int);

int main(void)
(
    char *inpname = "interin1"; /* file of raw sampled data */
    char *outname = "interpou"; /* File containing interpolated */
    /* data generated from this process. */

    FILE *fpi, *fpo;
    float temp; /* Temporary variable to hold unwanted information in input */
    /* file. */

    float Interp[COLS][ROWS]; /* Array for interpolated */
    /* solutions plus an extra row and column. */
    float ans[SIZE]; /* This vector will be used for the matrix */
    /* determination of weights relating to the neighbouring */
    /* sample points required for the determination of the */
    /* interpolated values. */
    /* The SIZE is the maximum number of neighbouring sample */
    /* points + 1 for langrangian unknown and 1 for luck. */
    float *nb; /* some as ans just translated for use with 'c' recipes. */

    float mat[SIZE][SIZE]; /* The matrix for determining the weights as in */
    /* mat.x = ans. */
    float **na; /* for translation of mat for 'c' recipes. */
    float var; /* Variable for the determination of an interpolated */
    /* point's minimum estimation variance. */

```

```

/* variables required by 'c' recipes */
int *indp;
float sign;
int num;

double col, row; /* indicates the point to be interpolated */
double onrow, oncol; /* A variable to indicate whether the */
/* interpolated point is on a row or column */
/* of the original sample grid. */
double intr, intrc; /* This variable indicates which previous */
/* row or column of the sample grid is closest */
/* to the interpolated point. */
double refrow, refcol; /* These variables will be used to indicate the */
/* position of a possible suitable neighbouring */
/* sample point to any particular interpolated */
/* point. */

int i, j; /* indexes to the mat matrix elements */
int k, l; /* spare indexing variables */
int num_neigh_samps; /* The number of neighbouring samples used for */
/* interpolation. */

int ct; /* Counter for the number of interpolated points. */
float x, y; /* A representation of the positions of the */
/* interpolated points. */

clrscr();

/* Open the samples data file for interpolation */
if((fpi = fopen(inpname, "r")) == NULL)
(
    printf("Can't open %s.\n", inpname);
    exit(1);
)
fseek(fpi, 0L, SEEK_SET);

/* Open a file for the output of semivariogram data */
if((fpo = fopen(outname, "w")) == NULL)
(
    printf("Can't open %s.\n", outname);
    exit(1);
)
fseek(fpo, 0L, SEEK_SET);

/* Assign a suitable matrix (mat) and vector (ans) for use with the 'c' */
/* recipes in that the first elements start from 1. */
na = matrix(1, SIZE, 1, SIZE);
nb = vector(1, SIZE);
indp = ivector(1, SIZE);

/* Read sample data into an array representing the rows and columns */
/* at which the samples were taken in the field. */
for(i=0; i<COLS; i++)
(
    for(j=0; j<ROWS; j++)

```

```

    }
}

/* i and j index the mat matrix from 0 to num_neigh_smpls - 1 */
/* The final column of the matrix is assigned here. */
for (k=0; k <= (num_neigh_smpls - 1); k++)
    mat[k][num_neigh_smpls] = 1;

mat[num_neigh_smpls][num_neigh_smpls] = 0;

/* The final row of the matrix is assigned here. */
for (k=0; k <= (num_neigh_smpls - 1); k++)
    mat[num_neigh_smpls][k] = 1;

/* Now mat is a square matrix [0..num_neigh_smpls], ans is the */
/* solution vector [0..num_neigh_smpls]. */
/* These vectors have to be translated into matrices */
/* [1..(num_neigh_smpls + 1)] for use with 'c' recipes for solving */
/* matrix equations and for the final solutions for lambda/weights */
/* for this Xo. */
for (k=0; k<num_neigh_smpls; k++)
    for (l=0; l<num_neigh_smpls; l++)
        na[k+1][l+1] = mat[k][l];

for (k=0; k <= num_neigh_smpls; k++)
    nb[k+1] = ans[k];

num = num_neigh_smpls + 1;

/* Use the recipes to solve for lambda/weights for Xo */
ludcmp(na,num,indp,&sign); /* decompose to its LU equivalent */
lubksb(na,num,indp,nb); /* solve the matrix equation */

interp[col][row] = 0;

/* Use the weights to calculate the interpolated value at Xo. */
for (k=1; k<=num_neigh_smpls; k++)
    interp[col][row] += nb[k]*z[k-1];

/* Calculate the minimum estimation variance relating to */
/* each interpolated point. */
var = nb[num_neigh_smpls + 1];

for (k=1; k<=num_neigh_smpls; k++)
    var += nb[k]*ans[k-1];

/* Write the interpolated solution to a file. */
fprintf(fpo,"%d %.3f %.4f %.4f \n ", ct++, x, y, interp[col][ro
w], var);
y=KRIGINT;

/* Update interpolated point's positioning information. */
if (y < -120)
{
    y = 0;

```

```

    x+=KRIGINT;
}

/* 'C' Recipe clean up */
free_matrix(na,1,SIZE,1,SIZE);
free_vector(indp,1,SIZE);
free_vector(nb,1,SIZE);

fclose(fpi);
fclose(fpo);
return 0;

void nrrerror(error_text)
char error_text[];
{
    void exit();

    fprintf(stderr,"Numerical Recipes run-time error...\n");
    fprintf(stderr,"%s\n",error_text);
    fprintf(stderr,"...now exiting to system...\n");
    exit(1);
}

float *vector(nl,nh)
int nl,nh;
{
    float *v;

    v=(float *)malloc((unsigned) (nh-nl+1)*sizeof(float));
    if (!v) nrrerror("allocation failure in vector()");
    return v-nl;
}

```

```

int **imatix(nrl,nrh,ncl,nch)
int nrl,nrh,ncl,nch;
(
    int i,**m;

    m=(int **)malloc((unsigned) (nrh-nrl+1)*sizeof(int*));
    if (!m) perror("allocation failure 1 in imatrix()");
    m -= nrl;

    for(i=nrl;i<nrh;i++) {
        m[i]=(int *)malloc((unsigned) (nch-ncl+1)*sizeof(int));
        if (!m[i]) perror("allocation failure 2 in imatrix()");
        m[i] -= ncl;
    }
    return m;
)

float **submatrix(a,oldrl,oldrh,oldcl,oldch,newrl,newcl)
float **a;
int oldrl,oldrh,oldcl,oldch,newrl,newcl;
(
    int i,j;
    float **m;

    m=(float **) malloc((unsigned) (oldrh-oldrl+1)*sizeof(float*));
    if (!m) perror("allocation failure in submatrix()");
    m -= newrl;

```

```

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for(i=oldrl,j=newrl;i<=oldrh;i++,j++) m[j]=a[i]+oldcl-newcl;

return m;
)

void free_vector(v,nl,nh)
float *v;
int nl,nh;
(
    free((char*) (v+nl));
)

void free_ivector(v,nl,nh)
int *v,nl,nh;
(
    free((char*) (v+nl));
)

void free_dvector(v,nl,nh)
double *v;
int nl,nh;
(
    free((char*) (v+nl));
)

void free_matrix(m,nrl,nrh,ncl,nch)

```

```

float **m;
int nrl,nrh,ncl,nch;
{
    int i;

    for(i=nrh;i>=nrl;i--) free((char*) (m[i]+ncl));
    free((char*) (m+nrl));
}

void free_dmatrix(m,nrl,nrh,ncl,nch)
double **m;
int nrl,nrh,ncl,nch;
{
    int i;

    for(i=nrh;i>=nrl;i--) free((char*) (m[i]+ncl));
    free((char*) (m+nrl));
}

void free_imatrix(m,nrl,nrh,ncl,nch)
int **m;
int nrl,nrh,ncl,nch;
{
    int i;

    for(i=nrh;i>=nrl;i--) free((char*) (m[i]+ncl));
    free((char*) (m+nrl));
}

```

```

void free_submatrix(b,nrl,nrh,ncl,nch)
float **b;
int nrl,nrh,ncl,nch;
{
    free((char*) (b+nrl));
}

float **convert_matrix(a,nrl,nrh,ncl,nch)
float *a;
int nrl,nrh,ncl,nch;
{
    int i,j,nrow,ncol;
    float **m;

    nrow=nrh-nrl+1;
    ncol=nch-ncl+1;
    m = (float **) malloc((unsigned) (nrow)*sizeof(float));
    if (!m) perror("allocation failure in convert_matrix()");
    m -= nrl;
    for(i=0,j=nrl;i<=nrow-1;i++,j++) m[j]=a+ncol*i-ncl;
    return m;
}

void free_convert_matrix(b,nrl,nrh,ncl,nch)
float **b;

```

```

)

#undef TINY
void lubksb(a,n,indx,b)
float **a,b[];
int n,*indx;
{
    int i,ii=0,ip,j;
    float sum;

    for (i=1;i<=n;i++) {
        ip=indx(i);
        sum=b[ip];
        b[ip]=b(i);
        if (ii)
            for (j=ii;j<=i-1;j++) sum -= a(i)[j]*b(j);
        else if (sum) ii=i;
        b(i)=sum;
    }
    for (i=n;i>=1;i--) {
        sum=b(i);
        for (j=i+1;j<=n;j++) sum -= a(i)[j]*b(j);
        b(i)=sum/a(i)[i];
    }
}
```

#include <math.h>

```
#define INT 30.0 /* the distance between samples */
#define DIV 4.0 /* the division of the sampled grid size for interpolation */
#define KRIGINT INT/DIV /* distance between interpolated points */
#define ROWS 5 /* rows in the sampled grid */
#define COLS 7 /* columns in the sampled grid */
#define SIZE 11 /* NO. OF NEIGHBOURING SAMPLES MAX */
#define SEMIVAR(D) ((D) < 157 ? 35.5014 + 3.168103*(D) : 533.3)/* definition */
/* of the semivariance function for a particular chemical */
/*define SEMIVAR(D) (.6026 + 80.6152*(1-exp(-(D)/38.9201))*/
```

```

    )
}

if ((oncol == 0) && ((prevcol - 1) >= 0))
{
    indxrow = prevrow;
    indxcol = prevcol - 1;
    (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);

    if ((prevrow + 1) <= (ROWS - 1))
    {
        indxrow = prevrow + 1;
        indxcol = prevcol - 1;
        (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);
    }

    return 0;
}

```

```

/* This function determines which samples are suitable to be used as */
/* neighbouring samples to the interpolated point. */
/* It also calls the suitable function to operate on that chosen sample */
/* point depending on the current application of this function. */
/* This function will also indicate the number of suitable */
/* neighbouring samples found. */

#include "krgcnst.h"

int samtst(int (*funcptr)(double dum1, double dum2, double dum3, double dum4, int
*dum5, float dum[]), double onrow, double oncol, double rowval, double colval, d
ouble prevrow, double prevcol, int *asum, float vector[])
{
    double indxcol, indxrow; /* Used for indicating a neighbouring sample */
    *asum = 0; /* Sum the number of suitable neighbouring points */
    /* position. */

    /* Call the passed function for the first suitable neighbouring */
    /* sample position. */
    (*funcptr)(rowval, colval, prevrow, prevcol, asum, vector);

    /* Determine whether the next possible sample position falls */
    /* within the area actually sampled and therefore passes as a */
    /* suitable neighbouring sample position. */
    if ((prevrow + 1) <= (ROWS - 1))
    {
        indxrow = prevrow + 1;
        indxcol = prevcol;
        (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);
    }

    /* test the other possible sample positions.... */
    if ((prevcol + 1) <= (COLS - 1))
    {
        indxrow = prevrow;
        indxcol = prevcol + 1;
        (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);

        if ((prevrow + 1) <= (ROWS - 1))
        {
            indxrow = prevrow + 1;
            indxcol = prevcol + 1;
            (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);
        }
    }

    if ((onrow == 0) && ((prevrow - 1) >= 0))
    {
        indxrow = prevrow - 1;
        indxcol = prevcol;
        (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);

        if ((prevcol + 1) <= (COLS - 1))
        {
            indxrow = prevrow - 1;
            indxcol = prevcol + 1;
            (*funcptr)(rowval, colval, indxrow, indxcol, asum, vector);
        }
    }
}

```



```
/* This program calculates the distance from each neighbouring point (Xi)*/
/* to every other neighbouring point (Xj) and determines the associated */
/* semivarance to write to the mat array (a:in this function). */

#include "krncnst.h"

int calca(double refrow, double refcol, double neighrow, double neighcol, int *aj
float a[])
{
    double dist;

    /* calc dist from Xi to Xj */
    dist = sqrt(pow((refcol - neighcol)*INT,2) + pow((refrow - neighrow)*INT,2));

    a[*aj] = SEMIVAR(dist);

    *aj += 1; /* add one to the number of neighbouring sample points */
    return 0;
}
```

```

/* This program works out the distance from Xo (an interpolated point) */
/* to the position of the neighbouring sample point on the sample */
/* grid (Xi) and stores the result of the associated semivariance value */
/* in the ans (b: in this case) vector. */
/* It also assigns the sample values (z vector) to neighbouring points */
/* (Xi's) of Xo for use in the final determination of interpolated */
/* values using the weights generated from the ans vector and mat array.*/

#include "krgrnst.h"
#include <math.h>

extern float z[]; /* sample values of the neighbouring points */
extern float sample[COLS][ROWS];

int calcb(double row, double col, double refrow, double refcol, int *asum, float
b[])
{
    double dist;

    z[*asum] = sample[(int)refcol][(int)refrow]; /* Assign the sample value */
        /* to a neighbouring sample point Xi. */

    /* calc dist from Xi to Xo */
    dist = sqrt(pow((refcol*DIV - col)*KRIGINT,2) + pow((refrow*DIV - row)*KRIGINT
,2));

    b[*asum] = SEMIVAR(dist);

    *asum += 1; /* add one to the number of neighbouring sample points to Xo */

    return 0;
}

```

G.3 Simulation Software

SERINTP.PRJ is the software that was used in the simulation phase of the project. This program uses interrupts on the serial port to access data being passed to it and to relate it to a graphics screen for viewing.

The following software printouts are all the programs in the SERINTP.PRJ project file.

```

/* This program reads data transmitted from a GPS receiver at 9600 baud
/* every second or so. This is done by interrupts and writing
/* the data to a ring buffer. Finally graphics is used to
/* display the data.
/* This program was used during simulation, with another computer
/* simulating the GPS data to be sent and in the actual testing of the
/* software in the lab with the real GPS receiver. */

```

```

#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <graphics.h>
#include "comm.h"
#include "comdes.h"

```

```

extern int respond (ASYNC *, char);
extern int setupscreen ();
extern int AllocRingBuffer (ASYNC *, int, int, int);

```

```

int main(void)
{

```

```

    ASYNC port; /* structure in comdes.h */
    /* Interrupt software in comm_s.lib */
    int rcode;
    char control = 'n';
    int xpos, ypos;

```

```

    setupscreen();
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    cleardevice();
    moveto(xpos, ypos);
    outtext("press any key for an updated version of input.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note: 'q' will terminate this session.");
    AllocRingBuffer(&port, RBUFSIZE, TBUFSIZE, FMEMFLG);

```

```

    rcode = async open(&port, COM1, COMINFO); /* Async Lib Fn */
    if (rcode != R_OK) /* rcode = RNOEM if alloc buffer failed */
    {
        printf("Async open failed, exit code = %d\n", rcode); /* errors to */
        printf("press any key to halt."); /* screen */
        getch(); /* nice way to let you pass to end a non recurring process */
        exit(rcode);
    } /* O.K. to exit because serial not open (hidden code) */

```

```

    while ((control != 'q') && (control != 'Q'))
    {
        while(!kbhit())
            continue;
        control = getch();
        respond(&port, control);
    }

```

```

/* Respond to an 'update of cyclic record from GPS receiver' request. */

#include <conio.h>
#include <graphics.h>
#include <string.h>
#include "comm.h"

extern int sbegin(ASYNC *, char *);

int respond(ASYNC *aport, char cntnl)
{
    int xpos, ypos;
    int rxch;
    char msg = 'n'; /* initialize */

    if ((cntnl != 'q') && (cntnl != 'Q'))
    {
        cleardevice();
        xpos = getmaxx() / 20;
        ypos = getmaxy() / 20;
        moveto(xpos, ypos);

        /* find the beginning of the cyclic report */
        sbegin(aport, &msg);

        /* write the report to the graphics screen */
        do
        {
            int index = 0;
            char str[135];

            /* Copy the received chars to a string and */
            /* the string to the screen. */
            strcpy(str, "");
            do
            {
                do
                {
                    rxch = async_rx(aport);
                } while ((rxch & B_REMPTY)); /* only pass if receive a */
                msg = rxch & 0xff;
                str[index++] = msg;
            } while (msg != '\n');
            str[index] = '\0';

            outtext(str);
            ypos += 10;
            moveto(xpos, ypos);
        } while (async_peek(aport, 0) != ' ');
    }

    return 0;
}

```

```
/* This function will set up the graphics screen. */

#include <graphics.h>
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>

int setupscreen(void)
{
    /* request auto detection */
    int gdriber = DETECT, gmode, errorcode;

    /* initialize graphics and local variables */
    initgraph(&gdriber, &gmode, "");

    /* read result of initialization */
    errorcode = graphresult();
    if (errorcode != grOk) /* an error occurred, print to screen */
    {
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt:");
        getch(); /* nice way to let you pass to end a non recurring process */
        exit(1); /* terminate with an error code */
    } /* O.K. to exit cause serial not yet open (hidden code) */

    cleardevice();
    settextstyle(SMALL_FONT, HORIZ_DIR, 4);

    return 0;
}
```

```

/* This file pre-initializes and allocates memory for the ring buffer */
/* required by the asynch_open function */

#if defined( _TURBOC )
#include <alloc.h>
#define _fmalloc farmalloc
#else
#include <malloc.h>
#endif
#include "comm.h"

int AllocRingBuffer(
    ASYNC *port,
    int rxsize,
    int txsize,
    int useFARmem)
(
    unsigned long memptr;
    int memsize;

    memsize = rxsize + txsize;

    if (useFARmem || sizeof(char *) == 4)
        memptr = (unsigned long)_fmalloc(memsize);
    else
        memptr = (unsigned long)(unsigned int)malloc(memsize);

    /* pre-initialize 4 required structure members */
    port->RxSize = rxsize;
    port->TxSize = txsize;
    port->RingSeg = (int)(memptr >> 16);
    port->RingOfst = (int)memptr;
    if (memptr == 0L)
        return 0;
    return 1;
}

/* pointer to port structure */
/* here port is an address */
/* number bytes to use for receive buffer */
/* number bytes to use for transmit buffer */
/* flag set if using FAR mem for buffers */

```

```
/* This function searches for the beginning of a GPS cyclic report record.*/

#include "comm.h"

int sbegin(ASYNC *aport, char *amesg)
{
    int rxch;

    async_rxflush(aport); /* Necessary not to lose chars due to */
                          /* re-initializing pointers to the */
                          /* beginning of the ring buffer when */
                          /* it is filled with chars. */

    for(;;)
    {
        do
        {
            if (!((rxch = async_rx(aport)) & B_RXEMPTY)) /* *aport here is an address */
                *amesg = (rxch & 0x7f); /* wait until get a char from */
                                      /* empty buffer and it is the */
                                      /* last char of the last record. */
        } while (*amesg != '\n');

        /* Peek at the next character in the ring buffer to check */
        /* that it is the first character of a record. */
        if (async_peek(aport, 0) == 'I')
            break;
    }

    return 0;
}
```


COMGEN1.PRJ was used on the transmitting side in which the computer read data similar to that from a GPS receiver and transmitted it asynchronously via the RS232 to the receiving computer.

The following software printouts are all the programs in the COMGEN1.PRJ project file.

```

/* This function reads characters from a text file simulating a GPS cyclic */
/* report and transmit the data asynchronously down the serial link. */

```

```

#include <bios.h>
#include <dos.h>
#include <conio.h>
#include <time.h>
#include <stdio.h>
#include <stdlib.h>
#include <serial.h>

int main(void)
{
    char signal;
    unsigned int err;
    unsigned int num = 0;
    FILE *fp;
    char *name = "gps"; /* file containing cyclic GPS report data */

    /*set up stdin stream for instructions and error messages*/
    clrscr();
    printf("\nPress any key to stop.\n");
    printf("This screen indicates functioning errors.\n");

    /*initialize com port*/
    num = bioscom(INIT,CONFIG,COM); /* bioscom initiates polled serial */
    if ((err = num & 0XFF00) != 0) /* operation on int #14 */
        printf("com_error_init %u.\n",err);

    /*open input file and goto begin*/
    if((fp = fopen(name,"r")) == NULL)
    {
        printf("Can't open %s.\n",name);
        exit(1);
    }
    fseek(fp,0L,SEEK_SET);

    /*loop until kb pressed*/
    do
    {
        /*get and send a signal until EOF*/
        while((signal = getc(fp)) != EOF)
        {
            num = bioscom(SEND,signal,COM);
        }
        rewind(fp);
    }while(!kbhit());
    /*close file and end*/
    fclose(fp);
    return 0;
}

```

The combination of COMGEN.PRJ and COMTALK.PRJ was trial simulation software similar to that of the above combination. In this case the software simply generated a string of characters for asynchronous transmission and used a polling mechanism on the receiving side to access the information.

The following software printouts are all the programs in the COMGEN.PRJ and COMTALK.PRJ project files.

```
/* this project simply generates a sequence of characters to transmit */
/* asynchronously down the serial link */
```

```
#include <bios.h>
#include <dos.h>
#include <conio.h>
#include <stdio.h>
#include "serial.h"
int main(void)
```

```
{
    char signal;
    unsigned int err;
```

```
    bioscom(INIT,238,COM);
    clrscr();
```

```
    /* printf("first enter a char for trans and a q if quit.\n");*/
```

```
    /* scanf("%c",&signal);*/
```

```
    signal = 'a';
```

```
    do
```

```
    {
```

```
        delay(2);
```

```
        bioscom(SEND,signal,COM);
```

```
    /* if ((err = bioscom(SEND,signal,COM) & 0xFF00) != 0)*/
```

```
    /* printf("comerrors %d.\n",err);*/
```

```
    printf("signal %c \n",signal);
```

```
    }while(scanf("%c",&signal) == 1 && signal != 'q');*/
```

```
    }while(signal++ != 'z');
```

```
    return 0;
```

```
}
```

```

/* This program extracts data from the serial port and */
/* outputs it to a graphics screen. This is part of the simulation */
/* process in which polling of the serial port using the bioscom */
/* instruction was used to obtain data from the port coming in at a set */
/* baud rate. */

#include <stdio.h>
#include <bios.h>
#include <conio.h>
#include <stdlib.h>
#include <graphics.h>
#include "serial.h"

extern char receive(void);

unsigned int num,err;

int main(void)
(
    char msg;
    extern unsigned int num,err;

    /* request auto detection for graphics screen */
    int gdriver = DETECT, gmode, errorcode;
    int xpos, ypos;

    /* initialize graphics and local variables */
    initgraph(&gdriver, &gmode, "");

    /* read result of initialization */
    errorcode = graphresult();
    if (errorcode != grOk) /* an error occurred */
    (
        printf("Graphics error: %s\n", grapherrormsg(errorcode));
        printf("Press any key to halt:");
        getch(); /* nice way to let you pass to end a non recurring process */
        exit(1); /* terminate with an error code */
    )

    cleardevice();
    settextstyle(SMALL_FONT, HORIZ_DIR, 3);
    xpos = getmaxx() / 10;
    ypos = getmaxy() / 10;
    moveto(xpos, ypos);
    outtext("Press any key for an updated version of input.");
    ypos += 20;
    moveto(xpos, ypos);
    outtext("Note : 'q' will terminate this session.");

    err = bioscom(INIT, CONFIG, COM); /* initialize serial port */
    if ((err = num & ERRMASK) != 0)
        printf("com_error_init %u.\n", err);

    for( ; )
    (
        while(!kbhit()) /* wait for an instruction from the keyboard */
            continue;

```

```

        if (getch() == 'q')
        (
            closegraph();
            exit(2);
        )

        /* print the received serial info to the graphics screen */
        cleardevice();
        xpos = getmaxx() / 20;
        ypos = getmaxy() / 20;
        moveto(xpos, ypos);

        do
        (
            msg = receive(); /* Testing control with mythical */
            /* character in simulation. */
            /* i.e. Wait until first char of report */
            /* received. */

            while (msg != '\n') /* i.e. while not end of GPS cyclic report */
            (
                int index = 0;
                char str[135];

                /* copy a line of chars to a string and the string to the screen */
                strcpy(str, "");
                do
                (
                    str[index++] = msg;
                    msg = receive();
                ) while ((msg != '\n') && (msg != '\0'));

                str[index++] = msg;
                str[index] = '\0';

                outtext(str);
                ypos += 10;
                moveto(xpos, ypos);
            )

        ) return 0;
    )

```

```
/* This function receives chars from the serial port and checks that */
/* it is operating properly. It also returns the char received. */

#include <bios.h>
#include <stdio.h>
#include "serial.h"
#define MASK 0377

char receive(void)
(
    extern unsigned int num,err;
    char signal;

    /* check the serial port */
    while ((bioscom(STAT,CONFIG,COM) & (unsigned int) 17) == 17)
        continue; /* use only if going to wait for setup report from GPS */

    num = bioscom(REC,CONFIG,COM);
    if ((err = num & ERRMASK) != 0)
        printf("com_error_rec %u.\n",err);

    num &= MASK;
    signal = (char) num;

    return (signal);
)
```

Appendix H

GPS Receiver Configuration

This is the printout of the set-up report of the GPS reference receiver for when the reference station was set up at the remote station (Trig Beacon). This print-out has been added for completeness only.

TRIMBLE NAVIGATION 4000RL REFERENCE LOCATOR - SERIAL NUMBER 3142A02382

SOFTWARE REVS: NAV-4.53 02/04/91 SIG-4.20 09/04/90 BOOT-2.00 21/11/89

CHANNELS INSTALLED: 12 L1 ONLY INTERNAL MEMORY: NONE

REFERENCE POSITION: 33:43.1999S 018:39.3797E +0117 meters

ELEVATION MASK: 05 degrees PDOP MASK: 20.0 SYNC TIME: 000.5 secs

DISABLED SVS: NONE

IGNORE HEALTH SVS: NONE

POSITION FIX MODES:

LAT/LON USING FIXED HEIGHT

CALIBRATION TIME: 010 secs

CODE CALIBRATION (meters):

+00.00 +00.13 -00.56 -00.57 +01.35 +01.13 +00.70 +00.96

+01.40 +00.04 +02.08 +01.72

JULIAN DAY 113 - FRI/23/APR/1993 - GPS WEEK 0693

This is the printout of the set-up report of the GPS reference receiver for when the reference station was set up at the homestead and powered from mains.

TRIMBLE NAVIGATION 4000RL REFERENCE LOCATOR - SERIAL NUMBER 3142A02382

SOFTWARE REVS: NAV-4.53 02/04/91 SIG-4.20 09/04/90 BOOT-2.00 21/11/89

CHANNELS INSTALLED: 12 L1 ONLY INTERNAL MEMORY: NONE

REFERENCE POSITION: 33:42.1174S 018:38.0915E +0101 meters

ELEVATION MASK: 06 degrees PDOP MASK: 20.0 SYNC TIME: 000.5 secs

SABLED SVS: NONE

NORE HEALTH SVS: NONE

SITION FIX MODES:

LAT/LON USING FIXED HEIGHT

LIBRATION TIME: 010 secs

DE CALIBRATION (meters):

+00.00 +00.72 -00.97 -00.44 +02.08 +02.02 +01.33 +01.74

+01.13 +01.12 +02.77 +02.79

LIAN DAY 114 - SAT/24/APR/1993 - GPS WEEK 0693

This is the printout of the set-up report of the GPS differential receiver for the tests carried out at the farm before any dynamic tests were carried out.

RIMBLE NAVIGATION 4000DL DIFFERENTIAL LOCATOR - SERIAL NUMBER 3141A02342

SOFTWARE REVS: NAV-4.53 02/04/91 SIG-4.20 09/04/90 BOOT-2.00 21/11/89

CHANNELS INSTALLED: 08 L1 ONLY INTERNAL MEMORY: NONE

REFERENCE POSITION: 30:35.6800S 017:51.5272E +0046 meters

ELEVATION MASK: 10 degrees PDOP MASK: 20.0 SYNC TIME: 002.0 secs

SABLED SVS: NONE

NORE HEALTH SVS: NONE

SITION FIX MODES:

LAT/LON/HEIGHT

LIBRATION TIME: 010 secs

IDE CALIBRATION (meters):

+00.00 +00.67 +00.43 +00.16 +00.93 +00.93 +00.83 +00.96

ELIAN DAY 113 - FRI/23/APR/1993 - GPS WEEK 0693

This is the printout of the set-up report of the GPS differential receiver for the tests carried out at the farm when it was re-configured for the dynamic tests.

TRIMBLE NAVIGATION 4000DL DIFFERENTIAL LOCATOR - SERIAL NUMBER 3141A02342

SOFTWARE REVS: NAV-4.53 02/04/91 SIG-4.20 09/04/90 BOOT-2.00 21/11/89

CHANNELS INSTALLED: 08 L1 ONLY INTERNAL MEMORY: NONE

REFERENCE POSITION: 30:35.6800S 017:51.5272E +0046 meters

ELEVATION MASK: 10 degrees PDOP MASK: 20.0 SYNC TIME: 001.0 secs

DISABLED SVS: NONE

IGNORE HEALTH SVS: NONE

POSITION FIX MODES:

LAT/LON/HEIGHT

CALIBRATION TIME: 010 secs

CODE CALIBRATION (meters):

+00.00 +00.67 +00.43 +00.16 +00.93 +00.93 +00.83 +00.96

JULIAN DAY 113 - FRI/23/APR/1993 - GPS WEEK 0693

Appendix I

GPS Cyclic Positioning Report

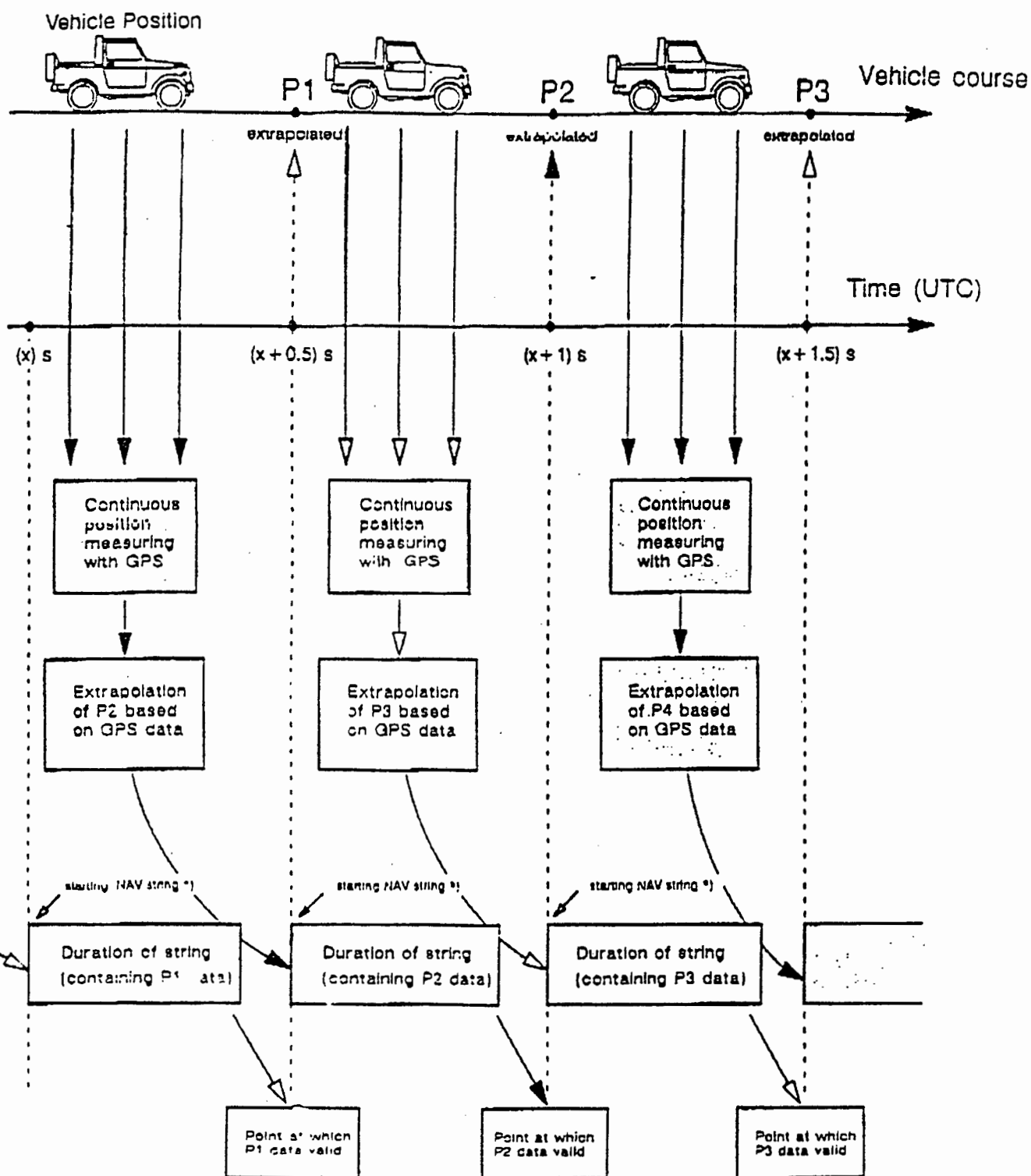
This is a representation of the 'Position Calculation' Cyclic Report generated by the GPS receiver.

```
SV EL AZM SN IODC CNT GPS.TIME
11 45 132 25 0610 0518 +499044.000
06 37 314 17 0166 0477 +499044.000
02 54 040 17 0203 0465 +499044.000
16 14 293 07 0379 0456 +499044.000
ID DAY DOY DATE TIME LATITUDE LONGITUDE HGT PDOP CLOCK V.VEL H.VEL HDG FREQ.OFFSET CNT S SVS
[00 FRI 173 22-JUN-90 18:37:19d37:23.6602N 122:02.2019W +0067 01.8 981657 +000.00 000.73 045.9 -1.27408-06 0457 3 11,6,2,15]
[00 FRI 173 22-JUN-90 18:37:20d37:23.6604N 122:02.3017W +0067 01.8 980386 +000.00 000.71 045.5 -1.27462-06 0458 3 11,6,2,15]
[00 FRI 173 22-JUN-90 18:37:21d37:23.6605N 122:02.3015W +0067 01.8 979114 +000.00 000.72 045.9 -1.27448-06 0459 3 11,6,2,15]
[00 FRI 173 22-JUN-90 18:37:22d37:23.6607N 122:02.3013W +0067 01.8 977843 +000.00 000.72 046.0 -1.27442-06 0460 3 11,6,2,15]
[00 FRI 173 22-JUN-90 18:37:23d37:23.6608N 122:02.3012W +0067 01.8 976572 +000.00 000.72 045.0 -1.27442-06 0461 3 11,6,2,15]
[00 FRI 173 22-JUN-90 18:37:24d37:23.6610N 122:02.3010W +0067 01.8 975301 +000.00 000.70 044.9 -1.27482-06 0462 3 11,6,2,15]
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SV EL AZM SN IODC CNT GPS.TIME
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06 37 314 18 0166 0487 +499054.000
02 54 040 18 0203 0475 +499054.000
16 14 293 04 0379 0466 +499054.000
ID DAY DOY DATE TIME LATITUDE LONGITUDE HGT PDOP CLOCK V.VEL H.VEL HDG FREQ.OFFSET CNT S SVS
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```

Appendix J

Theory Indicating the Timing of GPS Synchronization

This diagram represents the timing considerations in the generation of the synchronized output of GPS information.



*) max. jitter output (edge 1. character) : $\pm 10 ms$

Appendix K

Itinerary of Investigative Tour of the USA

The Investigation began with the ASAE Winter Meeting in Chicago Illinois in which up to date papers were presented on various topics of 'Site Specific Farming' or 'Prescription Farming'. Following the conference, a journey through Illinois and Missouri to both the state universities provided valuable insight into current research criteria and activity within this technology. This is due to the agronomic extensions which are attached to both these universities. As a result it is considered that these two institutions have done some of the best work in the country in Site Specific Farming.

Texas A&M has also done a fair amount of work in the past, however it was feasible to come up to date with their current ventures through contacts made at the conference itself.

Within the very specialized field of remote sensing applications for agriculture, a visit to the Space Remote Sensing (NASA Stennis Space Remote Sensing) Facility near Slidell in Mississippi was most beneficial.

Finally, a visit to both the Universities of Washington and Idaho proved valuable for their input into geostatistical and application research as well as for their practical experience with these technologies in the high yielding wheat farming of the Palouse area.

Appendix L

Analyzed Sample Data

The Kynoch Laboratory report for the soil samples taken during the tests, have been included in this appendix. These are agronomic results and served only as a basis for the statistics generated in this thesis. The emphasis of our work was to establish a way in which this data could be manipulated and represented to make it more useful for the agromomists to make recommendations for the field. Two dimensional GIS representations of the data were requested by the agronomists as an additional means of representing the data.



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LANDBOUDDIENSTE

KLANT: A. KIRSTEN
BUS 171
KERNKRAAG

ICOSNR: PROEF

GRONDONTLEDINGSVERSLAG

LANDBOUKUNDIGE: P.J. VAN VUUREN
VERTEENWOORDIGER: A. KIRSTEN
DATUM: 05/05/93

		ANWYNTUNASSET																VERSADIGINGS									
LABNR	NOHS	KAMPNAAM/HR	GR %	% C	KLEI %	SLIK %	SAND %	TEKSTUUR	WEERS	pH	CEC	EKS	P	P	K	Ca	Mg	Na	Cl	T-WDE	S-WDE	K	Ca	Mg	Na	BASE %	VERS
			VOL						Ohms	Kcl	me2	me2	DR-I	DR-II	DPH	DPH	DPH	DPH	DPH	me2	me2	%	%	%	%	%	
3536	1		0	0.60	0	0	0	SKL	0	5.2	0.00	0.56	36	0	72	535	59	16	0	3.98	3.42	4	67	12	1	85	
													me2		0.18	2.67	0.49	0.07									
3537	2		0	0.88	0	0	0	SKL	0	4.6	0.00	0.82	28	0	72	468	93	18	0	4.20	3.38	4	55	18	1	80	
													me2		0.18	2.34	0.76	0.08									
3538	3		0	0.76	0	0	0	SKL	0	4.3	0.00	1.06	44	0	45	386	58	17	0	3.66	2.60	3	52	13	2	71	
													me2		0.12	1.93	0.48	0.07									
3539	4		0	0.84	0	0	0	SKL	0	4.5	0.00	0.88	40	0	80	393	58	12	0	3.52	2.64	5	55	11	1	74	
													me2		0.21	1.97	0.42	0.05									
3540	5		0	0.92	0	0	0	SKL	0	4.3	0.00	1.19	36	0	89	425	77	14	0	4.25	3.06	5	50	15	1	71	
													me2		0.23	2.12	0.64	0.06									
3541	6		0	0.92	0	0	0	SKL	0	4.7	0.00	0.98	33	0	81	578	139	27	0	5.18	4.20	4	55	18	2	81	
													me2		0.21	2.89	0.98	0.12									
3542	7		0	0.72	0	0	0	SKL	0	5.0	0.00	0.68	60	0	37	520	62	99	0	4.32	3.64	2	60	11	9	84	
													me2		0.09	2.60	0.52	0.43									
3543	8		0	0.80	0	0	0	SKL	0	4.4	0.00	0.98	36	0	90	490	43	15	0	4.42	3.44	5	55	15	1	77	
													me2		0.23	2.45	0.67	0.07									
3544	9		0	0.68	0	0	0	SKL	0	4.6	0.00	0.82	26	0	52	490	37	20	0	4.23	3.41	3	57	17	2	80	
													me2		0.13	2.45	0.78	0.09									
3545	10		0	0.92	0	0	0	SKL	0	4.2	0.00	1.21	48	0	63	391	62	8	0	3.88	2.67	4	50	13	0	68	
													me2		0.16	1.96	0.52	0.03									
3546	11		0	0.76	0	0	0	SKL	0	4.1	0.00	1.31	41	0	87	434	93	17	0	4.55	3.24	4	47	17	1	71	
													me2		0.22	2.17	0.78	0.07									
3547	12		0	0.76	0	0	0	SKL	0	4.5	0.00	1.12	38	0	85	521	188	32	0	4.92	3.80	4	53	16	2	77	
													me2		0.22	2.60	0.63	0.14									
3548	13		0	0.88	0	0	0	SKL	0	7.1	0.00	0.00	64	0	46	1256	46	23	0	6.88	6.88	1	91	5	1	100	
													me2		0.12	6.28	0.38	0.10									
3549	14		0	0.96	0	0	0	SKL	0	4.1	0.00	1.35	41	0	70	368	27	9	0	3.98	2.63	4	46	14	0	66	
													me2		0.18	1.84	0.53	0.04									
3550	15		0	0.84	0	0	0	SKL	0	4.0	0.00	1.01	45	0	63	395	27	17	0	3.95	2.94	4	50	18	1	74	
													me2		0.16	1.98	0.72	0.07									

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AGRI-SERVICES
LANDBOUDDIENSTE

LANDBOUDKUNDE: P.J. VAN VUUREN
 VERTEENWOORDIGER: A. KIRSTEN
 DATUM: 05/05/93

LABNR	MONS	KAMPNAAM/NR	GR 2	Z C	KLEI2	SLIX2	SAND2	TEKSTUUR	WEERS	pH	CED	EKS	P	P	K	Ca	Mg	Na	CL	AMMONIUMSETAAT										VERSADIGINGS									
																				T-DE	S-DE	K	Ca	Mg	Na	BASE2	VERS												
			VOL						Obs	Ec1	ne2	ne2	BR-I	BR-II	DPH	3PH	3PH	DPH	3PH	ne2	ne2	Z	Z	Z	Z	Z	VERS												
3551	16		0	0.76	0	0	0	SKL	0	4.1	0.00	1.16	46	0	62	481	38	7	0	3.84	2.68	4	52	12	0	69													
													ne2	0.16	2.80	0.48	0.03																						
3552	17		0	0.60	0	0	0	SKL	0	4.5	0.00	0.85	29	0	57	429	54	10	0	3.63	2.78	4	59	12	1	76													
													ne2	0.15	2.15	0.45	0.04																						
3553	18		0	0.80	0	0	0	SKL	0	4.5	0.00	0.96	34	0	81	587	92	26	0	4.58	3.62	4	55	16	2	79													
													ne2	0.21	2.54	0.77	0.11																						
3554	19		0	0.84	0	0	0	SKL	445	5.3	0.00	0.58	62	0	53	528	188	138	0	4.86	4.28	2	54	18	12	88													
													ne2	0.14	2.64	0.90	0.60																						
3555	20		0	0.84	0	0	0	SKL	0	6.0	0.00	0.00	54	0	70	952	89	17	0	5.59	5.59	3	85	10	1	100													
													ne2	0.18	4.76	0.57	0.07																						
3556	21		0	0.64	0	0	0	SKL	0	7.2	0.00	0.00	47	0	55	2790	71	23	0	14.78	14.78	0	94	4	0	100													
													ne2	0.14	13.95	0.59	0.10																						
3557	22		0	0.72	0	0	0	SKL	0	6.8	0.00	0.00	36	0	57	1320	55	14	0	7.27	7.27	2	90	6	0	100													
													ne2	0.15	6.60	0.46	0.06																						
3558	23		0	0.76	0	0	0	SKL	0	4.5	0.00	0.89	32	0	64	516	98	22	0	4.48	3.59	3	57	16	2	80													
													ne2	0.16	2.58	0.75	0.10																						
3559	24		0	0.64	0	0	0	SKL	0	4.4	0.00	0.99	34	0	73	456	54	10	0	3.93	2.96	4	57	11	1	74													
													ne2	0.19	2.28	0.43	0.04																						
3560	25		0	0.96	0	0	0	SKL	0	4.5	0.00	0.93	70	0	55	433	42	18	0	3.66	2.73	3	59	9	2	74													
													ne2	0.14	2.17	0.35	0.08																						
3561	26		0	0.52	0	0	0	SKL	0	4.7	0.00	0.79	36	0	44	447	61	27	0	3.76	2.97	3	59	13	3	79													
													ne2	0.11	2.23	0.51	0.12																						
3562	27		0	0.56	0	0	0	SKL	0	4.5	0.00	0.82	31	0	47	427	46	13	0	3.52	2.70	3	60	10	1	76													
													ne2	0.12	2.13	0.38	0.06																						
3563	28		0	0.76	0	0	0	SKL	0	4.2	0.00	1.14	38	0	66	417	59	9	0	3.93	2.79	4	53	12	1	70													
													ne2	0.17	2.08	0.49	0.04																						
3564	29		0	0.72	0	0	0	SKL	0	4.8	0.00	0.84	35	0	68	517	51	9	0	4.06	3.22	4	63	10	0	79													
													ne2	0.17	2.58	0.42	0.04																						
3565	30		0	0.68	0	0	0	SKL	0	4.8	0.00	0.78	27	0	58	455	45	9	0	3.62	2.84	4	62	10	1	78													
													ne2	0.15	2.27	0.38	0.04																						

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LABNR	MONS	KAMPHAAR/HR	GR 2 : 2 C			KLEI2	SLIK2	SAND2	TEKSTUUR	WEERS	pH	CED	EKS	P	P	K	Ca	Mg	Na	Cl	T-WDE	S-WDE	K	Ca	Mg	Na	BASE2
			VOL																								
3566	31		0	0.92	0	0	0	0	SKL	0	4.7	0.00	0.74	61	0	60	470	43	13	0	3.66	2.92	4	64	9	1	79
3567	32		0	0.56	0	0	0	0	SKL	0	4.6	0.00	0.74	30	0	66	400	63	23	0	3.53	2.79	4	56	14	2	79
3568	33		0	0.56	0	0	0	0	SKL	0	5.1	0.00	0.59	23	0	48	486	42	9	0	3.53	2.94	3	68	9	1	83
3569	34		0	0.80	0	0	0	0	SKL	0	4.7	0.00	0.76	28	0	51	586	72	12	0	4.47	3.71	2	63	13	1	83
3570	35		0	0.64	0	0	0	0	SKL	0	4.6	0.00	0.84	28	0	45	486	61	10	0	3.94	3.10	2	61	12	1	78
3571	36		0	0.64	0	0	0	0	SKL	0	4.5	0.00	0.82	40	0	29	376	43	31	0	3.27	2.45	2	57	10	4	74
3572	37		0	0.56	0	0	0	0	SKL	0	7.5	0.00	0.00	42	0	41	2640	53	41	0	13.93	13.93	0	94	3	1	100
3573	38		0	0.48	0	0	0	0	SKL	0	6.8	0.00	0.00	30	0	27	854	31	20	0	4.68	4.68	1	91	5	1	100
3574	39		0	0.68	0	0	0	0	SKL	0	4.3	0.00	0.91	48	0	36	312	39	8	0	2.92	2.01	3	53	11	1	68
3575	40		0	0.76	0	0	0	0	SKL	0	4.3	0.00	0.98	35	0	45	403	40	8	0	3.48	2.50	3	57	9	1	71
3576	41		0	0.80	0	0	0	0	SKL	0	4.5	0.00	0.88	29	0	54	467	63	14	0	3.94	3.06	3	59	13	1	77
3577	42		0	1.08	0	0	0	0	SKL	0	5.0	0.00	0.77	23	0	101	503	99	33	0	4.51	3.74	5	55	18	3	82

Perc C

	0.60	0.72	0.88	0.84	0.96	0.92	0.5
	0.38	0.80	0.96	0.84	0.52	0.56	0.4
	0.76	0.68	0.84	0.64	0.56	0.56	0.68
	0.84	0.92	0.76	0.72	0.76	0.80	0.76
	0.92	0.76	0.60	0.76	0.72	0.64	0.80
0.92	0.76	0.80	0.64	0.68	0.64	1.08	

pH

5,2	5,0	7,1	5,3	4,5	4,7	7,5
4,6	4,4	4,1	6,0	4,7	4,6	6,8
4,3	4,6	4,0	7,2	4,5	5,1	4,3
4,5	4,2	4,1	6,8	4,2	4,7	4,3
4,3	4,1	4,5	4,5	4,8	4,6	4,5
4,7	4,5	4,5	4,4	4,8	4,5	5,0

Table 10

1.00	1.33	1.50	1.67	1.80	1.92	2.00
1.05	1.38	1.55	1.72	1.85	1.97	2.05
1.10	1.43	1.60	1.77	1.90	2.02	2.10
1.15	1.48	1.65	1.82	1.95	2.07	2.15
1.20	1.53	1.70	1.87	2.00	2.10	2.20
1.25	1.58	1.75	1.92	2.05	2.15	2.25
1.30	1.63	1.80	1.97	2.10	2.20	2.30
1.35	1.68	1.85	2.02	2.15	2.25	2.35
1.40	1.73	1.90	2.07	2.20	2.30	2.40
1.45	1.78	1.95	2.12	2.25	2.35	2.45
1.50	1.83	2.00	2.17	2.30	2.40	2.50
1.55	1.88	2.05	2.22	2.35	2.45	2.55
1.60	1.93	2.10	2.27	2.40	2.50	2.60
1.65	1.98	2.15	2.32	2.45	2.55	2.65
1.70	2.03	2.20	2.37	2.50	2.60	2.70
1.75	2.08	2.25	2.42	2.55	2.65	2.75
1.80	2.13	2.30	2.47	2.60	2.70	2.80
1.85	2.18	2.35	2.52	2.65	2.75	2.85
1.90	2.23	2.40	2.57	2.70	2.80	2.90
1.95	2.28	2.45	2.62	2.75	2.85	2.95
2.00	2.33	2.50	2.67	2.80	2.90	3.00

P (ppm)

36	60	64	62	70	61	42
28	36	41	54	36	30	30
44	26	45	47	31	23	48
40	43	46	36	38	28	35
36	41	29	32	35	23	29
33	38	34	34	27	40	23

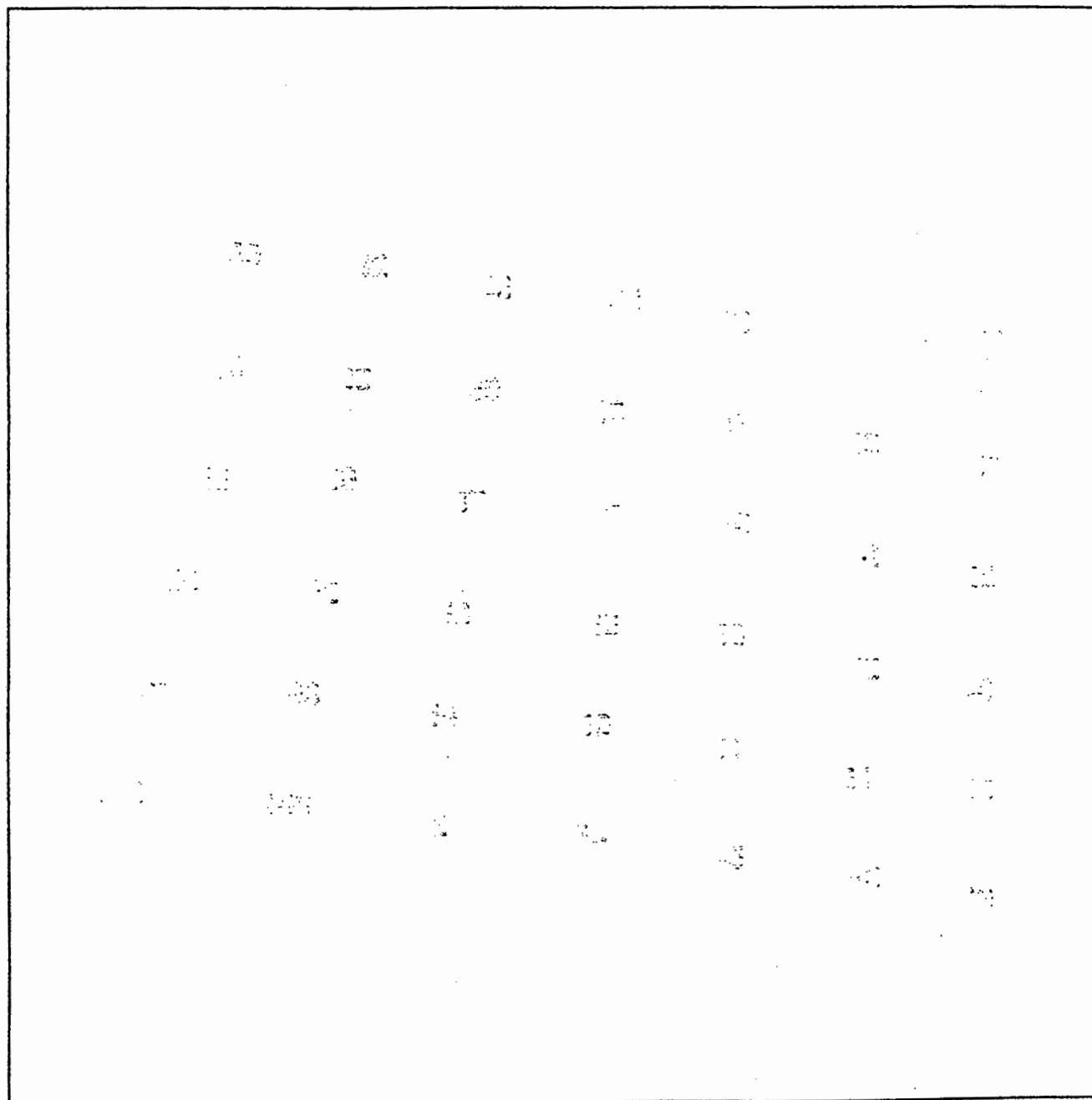
K (ppm)

72	37	46	53	55	60	41
72	90	70	70	44	66	27
45	52	63	55	47	48	36
80	63	62	57	66	51	45
39	87	57	64	68	45	54
31	85	81	73	58	29	101

Ca (ppm)

535 ⁺	520 ⁺	1256 ⁺	528 ⁺	433 ⁺	470 ⁺	2640 ⁺
468 ⁺	490 ⁺	368 ⁺	952 ⁺	447 ⁺	400 ⁺	854 ⁺
386 ⁺	490 ⁺	395 ⁺	2790 ⁺	427 ⁺	486 ⁺	312 ⁺
393 ⁺	391 ⁺	401 ⁺	1320 ⁺	417 ⁺	586 ⁺	403 ⁺
425 ⁺	434 ⁺	429 ⁺	516 ⁺	517 ⁺	486 ⁺	467 ⁺
578 ⁺	521 ⁺	507 ⁺	456 ⁺	455 ⁺	376 ⁺	503 ⁺

Fig. 100000



Perc. K

4	2	1	2	3	4	0
4	5	4	3	3	4	1
3	3	4	0	3	3	3
5	4	4	2	4	2	3
5	4	4	3	4	2	3
4	4	4	4	4	2	5

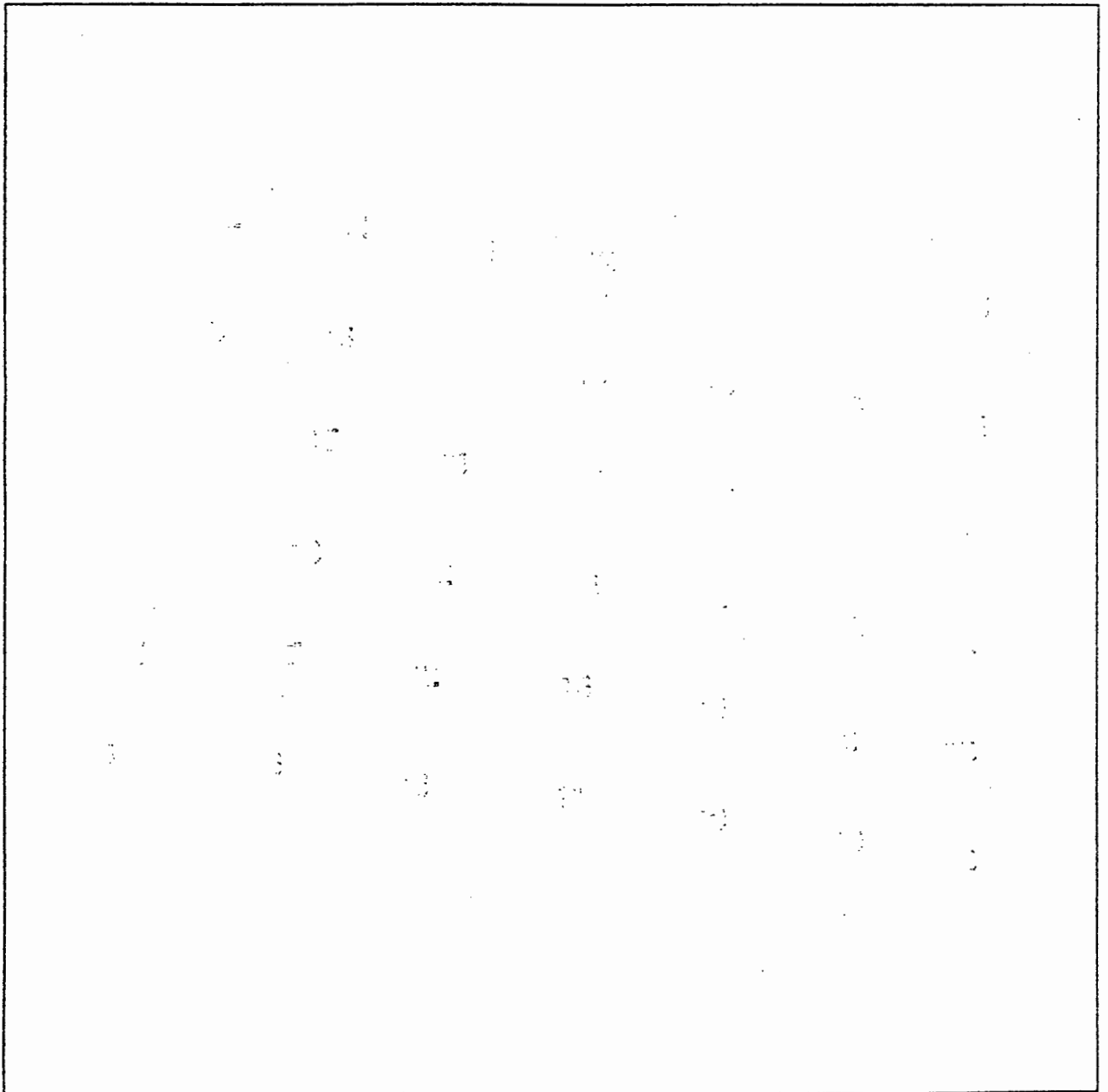
Na (ppm)

16	99	23	139	13	13	41
18	15	9	17	27	23	20
17	20	17	23	13	9	3
12	3	7	14	9	12	3
14	17	10	22	9	10	14
27	32	26	10	9	31	33

Perc. Ca

67	60	81	54	59	64	84
55	55	48	85	59	58	81
82	57	50	84	60	68	53
55	55	52	80	53	65	57
50	47	59	57	63	61	59
55	53	55	57	62	57	55

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Perc. Na

	1	9	1	12	2	1	1
	1	1	0	1	3	2	1
	2	2	1	0	1	1	1
	1	0	0	0	1	1	1
	1	1	1	2	0	1	1
2		2	2	1	1	4	3



pH

P (ppm)